SEISMIC HAZARD ZONE REPORT 048

SEISMIC HAZARD ZONE REPORT FOR THE CALAVERAS RESERVOIR 7.5-MINUTE QUADRANGLE, SANTA CLARA COUNTY, CALIFORNIA

2001

DEPARTMENT OF CONSERVATION
Division of Mines and Geology

STATE OF CALIFORNIA
GRAY DAVIS
GOVERNOR

THE RESOURCES AGENCY
MARY D. NICHOLS
SECRETARY FOR RESOURCES

DEPARTMENT OF CONSERVATION
DARRYL YOUNG
DIRECTOR

DIVISION OF MINES AND GEOLOGY
JAMES F. DAVIS, *STATE GEOLOGIST*

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EXECUTIVE SUMMARY

This report summarizes the methods and sources of information used to prepare the Seismic Hazard Zone Map for the Santa Clara County portion of the Calaveras Reservoir 7.5-minute Quadrangle. The map displays the boundaries of Zones of Required Investigation for liquefaction and earthquake-induced landslides over approximately 51 square miles at a scale of 1 inch = 2,000 feet.

The Calaveras Reservoir Quadrangle covers approximately 60 square miles in the southeastern San Francisco Bay Area. More than 80% of the area lies within Santa Clara County. The map includes parts of the City of San Jose and the City of Milpitas as well as unincorporated Santa Clara County land. Approximately 13,000 acres of watershed lands surrounding Calaveras Reservoir that are owned and managed by the City of San Francisco also lie within the quadrangle. Most of the area is steeply sloping terrain on the southwestern flank of the Diablo Range that borders the gently sloping part of Santa Clara Valley, which extends into the southwestern corner of the map.

The map is prepared by employing geographic information system (GIS) technology, which allows the manipulation of three-dimensional data. Information considered includes topography, surface and subsurface geology, borehole data, historical ground-water levels, existing landslide features, slope gradient, rock-strength measurements, geologic structure, and probabilistic earthquake shaking estimates. The shaking inputs are based upon probabilistic seismic hazard maps that depict peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years.

Much of the Santa Clara County portion of the Calaveras Reservoir Quadrangle is hilly to mountainous terrain. Several geologic map units within this area are weak and are very susceptible to landsliding. Other geologic map units are strong and less susceptible to landsliding. Earthquake-induced landslide hazard zones are mapped primarily within belts of weak rock that extend through the map area. Approximately 56% of the upland terrain has been included within the earthquake-induced landslide hazard zone. Liquefaction zones are limited to creek bottoms, the floor of Calaveras Valley south of Calaveras Reservoir, and part of the Santa Clara Valley floor in the southwestern part of the quadrangle.

How to view or obtain the map

Seismic Hazard Zone Maps, Seismic Hazard Zone Reports and additional information on seismic hazard zone mapping in California are available on the Division of Mines and Geology's Internet page: http://www.conservation.ca.gov/dmg/shezp/

Paper copies of Official Seismic Hazard Zone Maps, released by DMG, which depict zones of required investigation for liquefaction and/or earthquake-induced landslides, are available for purchase from:

BPS Reprographic Services
149 Second Street
San Francisco, California 94105
(415) 512-6550

Seismic Hazard Zone Reports (SHZR) summarize the development of the hazard zone map for each area and contain background documentation for use by site investigators and local government reviewers. These reports are available for reference at DMG offices in Sacramento, San Francisco, and Los Angeles. **NOTE: The reports are not available through BPS Reprographic Services.**

INTRODUCTION

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate seismic hazard zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the seismic hazard zone maps in their land-use planning and permitting processes. They must withhold development permits for a site within a zone until the geologic and soil conditions of the project site are investigated and appropriate mitigation measures, if any, are incorporated into development plans. The Act also requires sellers (and their agents) of real property within a mapped hazard zone to disclose at the time of sale that the property lies within such a zone. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.conservation.ca.gov/dmg/pubs/sp/117/).

The Act also directs SMGB to appoint and consult with the Seismic Hazards Mapping Act Advisory Committee (SHMAAC) in developing criteria for the preparation of the seismic hazard zone maps. SHMAAC consists of geologists, seismologists, civil and structural engineers, representatives of city and county governments, the state insurance commissioner and the insurance industry. In 1991 SMGB adopted initial criteria for delineating seismic hazard zones to promote uniform and effective statewide implementation of the Act. These initial criteria provide detailed standards for mapping regional liquefaction hazards. They also directed DMG to develop a set of probabilistic seismic maps for California and to research methods that might be appropriate for mapping earthquake-induced landslide hazards.

In 1996, working groups established by SHMAAC reviewed the prototype maps and the techniques used to create them. The reviews resulted in recommendations that 1) the process for zoning liquefaction hazards remain unchanged and 2) earthquake-induced landslide zones be delineated using a modified Newmark analysis.

This Seismic Hazard Zone Report summarizes the development of the hazard zone map. The process of zoning for liquefaction uses a combination of Quaternary geologic mapping, historical ground-water information, and subsurface geotechnical data. The process for zoning earthquake-induced landslides incorporates earthquake loading, existing landslide features, slope gradient, rock strength, and geologic structure. Probabilistic seismic hazard maps, which are the underpinning for delineating seismic hazard zones, have been prepared for peak ground acceleration, mode magnitude, and mode distance with a 10% probability of exceedance in 50 years (Petersen and others, 1996) in accordance with the mapping criteria.

This report summarizes seismic hazard zone mapping for potentially liquefiable soils and earthquake-induced landslides in the Calaveras Reservoir 7.5-minute Quadrangle.

SECTION 1
LIQUEFACTION EVALUATION REPORT

Liquefaction Zones in the Calaveras Reservoir 7.5-Minute Quadrangle, Santa Clara County, California

By
Kevin B. Clahan, Elise Mattison, and Anne M. Rosinski

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps developed by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within seismic hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines adopted by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.conservation.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for potentially liquefiable soils in the Calaveras Reservoir 7.5-minute Quadrangle. This section, along with Section 2 (addressing earthquake-induced landslides), and Section 3 (addressing potential ground shaking), form a report that is one of a series that summarizes production of similar seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazards zone mapping in California is on DMG's Internet web page: http://www.conservation.ca.gov/dmg/shezp/

BACKGROUND

Liquefaction-induced ground failure historically has been a major cause of earthquake damage in northern California. During the 1989 Loma Prieta earthquake and the 1906 San Francisco earthquake, significant damage to roads, utility pipelines, buildings, and other structures in the San Francisco Bay area was caused by liquefaction-induced ground displacement.

Localities most susceptible to liquefaction-induced damage are underlain by loose, water-saturated, granular sediment within 40 feet of the ground surface. These geological and ground-water conditions are widespread in the San Francisco Bay Area, most notably in some densely populated valley regions and alluviated floodplains. In addition, the potential for strong earthquake ground shaking is high because of the many nearby active faults. The combination of these factors constitutes a significant seismic hazard, especially in areas marginal to San Francisco Bay, including areas in the Calaveras Reservoir Quadrangle.

METHODS SUMMARY

Characterization of liquefaction hazard presented in this report requires preparation of maps that delineate areas underlain by potentially liquefiable sediment. The following were collected or generated for this evaluation:

- Existing geologic maps were used to provide an accurate representation of the spatial distribution of Quaternary deposits in the study area. Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial and fluvial sedimentary deposits and artificial fill
- Construction of shallow ground-water maps showing the historically highest known ground-water levels
- Quantitative analysis of geotechnical data to evaluate liquefaction potential of deposits
- Information on potential ground shaking intensity based on DMG probabilistic shaking maps

The data collected for this evaluation were processed into a series of geographic information system (GIS) layers using commercially available software. The liquefaction zone map was derived from a synthesis of these data and according to criteria adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

Evaluation for potentially liquefiable soils generally is confined to areas covered by Quaternary (less than about 1.6 million years old) sedimentary deposits. Such areas consist mainly of alluviated valleys and canyon regions. DMG's liquefaction hazard evaluation is based on information on earthquake ground shaking, surface and subsurface lithology, geotechnical soil properties, and ground-water depth. These data are gathered from a variety of sources. Although selection of data used in this evaluation was rigorous, the quality of the data used varies. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data obtained from outside sources.

Liquefaction zone maps are intended to prompt more detailed, site-specific geotechnical investigations, as required by the Act. As such, liquefaction zone maps identify areas where the potential for liquefaction is relatively high. They do not predict the amount or direction of liquefaction-related ground displacements, or the amount of damage to facilities that may result from liquefaction. Factors that control liquefaction-induced ground failure are the extent, depth, density, and thickness of liquefiable materials, depth to ground water, rate of drainage, slope gradient, proximity to free faces, and intensity and duration of ground shaking. These factors must be evaluated on a site-specific basis to assess the potential for ground failure at any given project site.

Information developed in the study is presented in two parts: physiographic, geologic, and hydrologic conditions in PART I, and liquefaction and zoning evaluations in PART II.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Calaveras Reservoir 7.5-minute Quadrangle includes approximately 60 square miles of land in Alameda and Santa Clara counties, along the southeastern margin of San Francisco Bay. The boundary between Alameda and Santa Clara counties trends east-west through the northern portion of the quadrangle. Approximately 8 square miles (13 percent of the quadrangle) along the northern boundary of the quadrangle is within Alameda County. This evaluation report, and accompanying Seismic Hazard Map cover only that portion of the quadrangle that is within Santa Clara County.

The cities of San Jose and Milpitas occupy the southwestern part of the quadrangle. The northeastern half of the quadrangle is unincorporated, mostly undeveloped, and lies largely within lands owned or managed by the San Francisco City Water Department as watershed for the Calaveras Reservoir. Calaveras Reservoir is impounded behind an earthfill dam across Calaveras Creek in the north-central portion of the quadrangle.

The Calaveras Reservoir Quadrangle is dominated by the steep, northwest-trending Diablo Range. The southwest-sloping foothills of this range trend northwest from the southeastern boundary of the quadrangle to the northwest corner of the quadrangle. Calaveras Reservoir lies within the Calaveras Valley between the Calaveras Creek watershed to the east and the Santa Clara Valley and San Francisco Bay plain to the west. Three perennial streams, Penitencia Creek, Arroyo Aguague, and Berryessa Creek, and several intermittent streams flow southwestward from the foothills and are tributaries to the San Francisco Bay and the low-gradient streams of the Santa Clara Valley.

The only major highway in the quadrangle is Interstate 680. Trending subparallel to the foothills, it crosses the southwest corner of the quadrangle. Several secondary roads provide access along the foothills. Road access in the northeastern half of the quadrangle is limited to a few paved roads and more common unsurfaced ranch roads.

GEOLOGY

Geologic Mapping

Geologic units that generally are susceptible to liquefaction include late Quaternary alluvial sedimentary deposits and artificial fill. To identify and characterize deposits susceptible to liquefaction in the Calaveras Reservoir Quadrangle, recently completed maps of the nine-county San Francisco Bay Area showing Quaternary deposits (Knudsen and others, 2000) and bedrock units (Wentworth and others, 1999) were obtained from the U.S. Geological Survey in digital form. These Geographic Information System (GIS) maps were combined, with minor modifications along the bedrock/Quaternary contact, to form a single 1:24,000-scale geologic map of the Calaveras Reservoir Quadrangle. This map (Plate 1.1) was used to evaluate liquefaction susceptibility and develop the Seismic Hazard Zone Map.

The Quaternary geologic mapping methods described by Knudsen and others (2000) consist of interpretation of topographic maps, aerial photographs, and soil surveys, as well as compiled published and unpublished geologic maps. The authors estimate the ages of deposits using: landform shape, relative geomorphic position, crosscutting relationships, superposition, depth and degree of surface dissection and relative degree of soil profile development. Table 1.1 compares stratigraphic nomenclature used in Knudsen and others (2000) with that of several previous studies performed in northern California.

Other geologic maps and reports were reviewed to evaluate the areal and vertical distribution of shallow Quaternary deposits and to provide information on subsurface geologic, lithologic and engineering properties of the map units. Among the references consulted were Crittenden (1951), California Department of Water Resources (1967), Helley and Brabb (1971), Poland (1971), Nilsen and Brabb (1972), Brown and Jackson (1973), Cooper-Clark and Associates (1974), Rogers and Williams (1974), Atwater and others (1976), Helley and others (1979), Falls (1988), Helley (1990), Geomatrix Consultants Inc. (1992a, 1992b), and Helley and others (1994). Limited field reconnaissance was conducted to confirm the location of geologic contacts, map recently modified ground surfaces, observe properties of near-surface deposits, and characterize the surface expression of individual geologic units.

UNIT	Knudsen and others (2000)	Helley and others (1994)	Helley and others (1979)	Wentworth and others (1999)	DMG GIS database
Artificial fill	af			af	af
Artificial stream channel	ac				ac
Modern stream channel deposits	Qhc	Qhsc	Qhsc	Qhc	Qhc
Holocene alluvial fan deposits	Qhf	Qhaf, Qhfp	Qham, Qhac	Qhf, Qhfp	Qhf
Holocene stream terrace deposits	Qht	Qhfp		Qht	Qht
Holocene alluvium, undifferentiated	Qha			Qha	Qha
Latest Pleistocene to Holocene stream terrace deposits	Qt				Qt
Latest Pleistocene to Holocene alluvium, undifferentiated	Qa			Qa	Qa
Latest Pleistocene alluvial fan deposits	Qpf	Qpaf		Qpf	Qpf
Latest Pleistocene alluvium, undifferentiated	Qpa	Qpaf	Qpa	Qpa	Qpa
Early to late Pleistocene undifferentiated alluvial deposits	Qoa	Qru, Qrl	Qpea, Qpmc	Qpa	Qoa
bedrock	br	Br			br

Table 1.1. Correlation Chart of Quaternary Stratigraphic Nomenclatures Used in Previous Studies. For this study, DMG has adopted the nomenclature of Knudsen and others (2000).

Regional Geology

Bedrock in the Calaveras Reservoir Quadrangle consists of a sequence of igneous, metamorphic, and sedimentary rocks of late Mesozoic/earliest Cenozoic and middle to late Cenozoic age. The Calaveras Fault Zone juxtaposes two distinct structural domains (Wentworth and others, 1999). East of the Calaveras Fault Zone, the study area is predominantly composed of Cretaceous and Jurassic Franciscan Complex, primarily consisting of sheared shale and metagraywacke. West of the Calaveras Fault Zone, the study area is composed of Jurassic to Quaternary sedimentary units that overlie Jurassic

Coast Range ophiolite (Wentworth and others, 1999). See the Earthquake Induced Landslide portion (Section 2) of this report for further details.

The Calaveras Reservoir Quadrangle is within the active San Andreas Fault system, which distributes shearing across a complex system of northwest-trending, right-lateral, strike-slip faults that include the Hayward and Calaveras faults. From just west of the Cherry Flat Reservoir in the southeastern part of the quadrangle, the Calaveras Fault Zone trends northwest beneath Calaveras Reservoir. In the southwestern part of the quadrangle, the Hayward Fault extends along the base of the foothills. Historical ground-rupturing earthquakes have occurred on both of these faults (Lawson, 1908; Keefer and others, 1980).

Surficial Geology

In the Calaveras Reservoir Quadrangle, there are 11 Quaternary map units covering approximately 18 square miles (30 percent) of the study area. Most of the mapped Quaternary deposits are within the Santa Clara Valley in the southwestern portion of the quadrangle. In the remainder of the quadrangle, Quaternary deposits are scattered throughout the Diablo Range and occur primarily within small valleys.

Material not deposited as a result of geologic processes, whether engineered or not, is mapped as artificial fill (af). Artificial fill is typically associated with large structures such as the Calaveras Reservoir. Modern stream channel deposits (Qhc) are composed of loose, unconsolidated mixtures of sand, gravel, and cobbles, with minor silt and clay, and are associated with Upper Penitencia Creek and Berryessa Creek. These perennial streams originate in the foothills of the Diablo Range and deposit sediment along the margins of Santa Clara Valley as Holocene alluvial fan deposits (Qhf). Holocene alluvial fan deposits (Qhf) are characterized by moderately to poorly sorted sand, gravel, silt and clay. In the Calaveras Reservoir Quadrangle, particle size generally decreases to the west, as fans grade into the alluvium on the floor of the Santa Clara Valley. As a flood control measure to accommodate heavier flows in the winter months, portions of several streams have been confined within artificial stream channels (ac) that may be as much as 30 feet deep and may have artificial levees along their banks. Holocene stream terrace deposits (Qht) that consist of unconsolidated sand, gravel, silt and minor clay accumulate along perennial and intermittent streams. Where stream courses encounter an abrupt change in gradient, such as at the southern end of the Calaveras Reservoir, complex depositional environments occur and the resulting highly variable deposits are simply mapped as undifferentiated Holocene alluvium (Qha). Within the quadrangle, some steep, narrow areas adjacent to active streams are mapped as latest Pleistocene to Holocene stream terrace deposits (Qt) that are composed primarily of sand and gravel, whereas linear valleys cut by small, active, stream channels accumulate undifferentiated latest Pleistocene to Holocene alluvium (Qa).

Within the limits of the Calaveras Reservoir Quadrangle, the oldest mapped Quaternary deposits are latest Pleistocene alluvial fans (Qpf) and undifferentiated alluvium (Qpa), and early to latest Pleistocene undifferentiated alluvium (Qoa).

ENGINEERING GEOLOGY

Subsurface Geology and Geotechnical Characteristics

Geotechnical and environmental borehole logs provided descriptions of lithologic and engineering characteristics of Quaternary deposits within the study area. All materials identified in the borehole logs were assigned unit names based on the unit descriptions of Knudsen and others (2000) as well as characteristics identified in the field. Summaries of geotechnical characteristics of the units as interpreted from the GIS database are presented in Tables 1.2 and 1.3.

Compilation of Geotechnical Borehole Data

Information on subsurface geology and engineering characteristics of flatland deposits was obtained from borehole logs collected from reports on geotechnical and environmental projects. For this investigation, about 20 borehole logs were collected from the files of the California Department of Transportation and the public works and engineering departments of the cities of San Jose and Milpitas. Data from 16 borehole logs were entered into a DMG geotechnical GIS database (Table 1.2, Plate 1.2). This database is used to assess the susceptibility of subsurface materials to earthquake-induced liquefaction. Additional ground-water information from five boreholes within the Calaveras Reservoir Quadrangle was obtained from the Santa Clara Valley Water District, Underground Storage Tank Monitoring Program.

Standard Penetration Test (SPT) data provide a standardized measure of the penetration resistance of a geologic deposit, and are commonly used as an index of density. Geotechnical investigations record SPT data, including the number of blows by a 140 lb. drop weight required to drive a sampler of specific dimensions into the soil one foot. Recorded blow counts for acceptable non-SPT geotechnical sampling, where the sampler diameter, hammer weight or drop distance differ from those specified for a SPT (ASTM D 1586), were converted to SPT blow counts and entered into the DMG GIS. The actual and converted SPT blow counts were normalized using an effective overburden pressure and adjusted for equipment and operational procedures using a method described by Seed and Idriss (1982) and Seed and others (1985). Different blow count corrections are used for silty sand and nonplastic silt than for clean sand (Seed and others, 1985). This normalized blow count is referred to as $(N_1)_{60}$.

GEOLOGIC MAP UNIT		DRY DENSITY (pounds per cubic foot)						STANDARD PENETRATION RESISTANCE (blows per foot, $(N_1)_{60}$)					
Unit (1)	Texture (2)	Number of Tests	Mean	CV (3)	Median	Min	Max	Number of Tests	Mean	CV (3)	Median	Min	Max
Af	Fine	1	110	-	110	110	110	5	29	0.19	28	22	37
	Coarse	1	115	-	115	115	115	7	26	0.29	26	16	38
Qhf	Fine	13	108.1	0.07	110.3	87	116	19	21	0.94	17	2	87
	Coarse	4	106.3	0.10	102.5	98	122	15	40	0.61	36	10	104
Qpf	Fine	3	113.9	0.06	115.0	107	120	12	31	1.34	15	6	144
	Coarse	5	114.4	0.05	114.0	107	124	12	51	0.52	48	12	85

Notes:

(1) See Table 1.3 for names of the units listed here.

(2) Fine soils (silt and clay) contain a greater percentage passing the #200 sieve (<0.074 mm); coarse soils (sand and gravel) contain a greater percentage not passing the #200 sieve.

(3) CV = coefficient of variation (the standard deviation divided by the mean).

Table 1.2. Summary of Geotechnical Characteristics for Quaternary map units in the Calaveras Reservoir Quadrangle.

Geologic Unit (1)	Description	Number Of Records	Composition by Soil Type (Unified Soil Classification System Symbols)	Depth to ground water (ft) (2) and liquefaction susceptibility category assigned to geologic unit			
				<10	10 to 30	30 to 40	>40
af	Artificial fill (3)	6	CL 50%; CL-CH 17% SC 17%; SM-ML 17%	VH - L	H - L	M - L	VL
ac	Artificial stream channel	0		VH - L	H	M	VL
Qhc	Modern stream channel deposits	0		VH	H	M	VL
Qhf	Holocene alluvial fan deposits	42	CL 33%; ML 14% SP 10%; SM 7%; Other 36%	H	M	L	VL
Qht	Holocene stream terrace deposits	0		H	H	M	VL
Qha	Holocene alluvium, undifferentiated	0		M	M	L	VL
Qf	Late Pleistocene to Holocene alluvial fan deposits	2	CL 100%	M	L	L	VL
Qt	Late Pleistocene to Holocene stream terrace deposits	0		M	L	L	VL
Qa	Late Pleistocene to Holocene alluvium, undifferentiated	0		M	L	L	VL
Qpf	Late Pleistocene alluvial fan deposits	28	CL 46%; SC 18%; SP 7%, SM 7%; ML 7%; Other 15%	L	L	VL	VL
Qpa	Undifferentiated late Pleistocene alluvium	0		L	L	VL	VL
Qoa	Early to middle Pleistocene alluvium, undifferentiated	0		L	L	VL	VL
B	Bedrock	n/a	n/a (4)	VL	VL	VL	VL

Notes:
(1) Susceptibility assignments are specific to the materials within the Calaveras Reservoir 7.5-minute Quadrangle.
(2) Based on the Simplified Seed Procedure (Seed and Idriss, 1971; Youd and Idriss, 1997) and a small number of borehole analyses for some units.
(3) The liquefaction susceptibility of artificial fill ranges widely, depending largely on the nature of the fill, its age, and whether it was compacted during emplacement.
(4) n/a = not applicable

Table 1.3. Liquefaction Susceptibility for Quaternary Map units in the Calaveras Reservoir Quadrangle. Units indicate relative susceptibility of deposits to liquefaction as a function of material type and ground-water depth within that deposit. VH = very high, H = high, M = moderate, L = low, and VL = very low to none.

GROUND-WATER CONDITIONS

Liquefaction hazard may exist in areas where depth to ground water is 40 feet or less. Accordingly, ground-water conditions were investigated in the Calaveras Reservoir Quadrangle to evaluate the depth to saturated sediment. Saturated conditions reduce the effective normal stress, thereby increasing the likelihood of earthquake-induced liquefaction (Youd, 1973). The evaluation of ground-water levels was based on first-encountered water noted in geotechnical borehole logs acquired from the cities of San Jose and Milpitas, as well as water-level data provided by the Santa Clara Valley Water District. The depths to first-encountered water free of piezometric influences were plotted on a map of the project area showing depths to historically shallowest ground water (Plate 1.2). Depth to the water surface in stream channels, creeks, and drainage ditches was observed in the field; these measurements were used to calibrate and validate the historically high ground-water map.

DMG uses the historically highest known ground-water levels because water levels during an earthquake cannot be anticipated due to the unpredictable fluctuations caused by natural processes and human activities. An historically high ground-water map differs from most ground-water maps, which show the actual water table at a particular time; Plate 1.2 depicts a hypothetical ground-water table. Ground-water levels are presently at or near their historical highs in many areas of the Santa Clara Valley (Seena Hoose, SCVWD, oral communication, 2000).

Depths to first-encountered water range from 34 to 100 feet below the ground surface of the Santa Clara Valley and nearly all of the study area has ground-water levels greater than 30 feet below the ground surface (Plate 1.2). Ground-water levels deepen to the northeast, towards the base of the foothills. The southern part of Calaveras Valley has been assigned ground-water depths of greater than 20 feet based on the depths of entrenched drainages and the presence of Calaveras Reservoir.

PART II

LIQUEFACTION HAZARD POTENTIAL

Liquefaction may occur in water-saturated sediment during moderate to great earthquakes. Liquefied sediment loses strength and may fail, causing damage to buildings, bridges, and other structures. Many methods for mapping liquefaction hazard have been proposed. Youd (1991) highlights the principal developments and notes some of the widely used criteria. Youd and Perkins (1978) demonstrate the use of geologic criteria as a qualitative characterization of liquefaction susceptibility and introduce the mapping technique of combining a liquefaction susceptibility map and a liquefaction opportunity map to produce a liquefaction potential map. Liquefaction susceptibility is a function of the capacity of sediment to resist liquefaction. Liquefaction opportunity is a function of the potential seismic ground shaking intensity.

The method applied in this study for evaluating liquefaction potential is similar to that of Tinsley and others (1985). Tinsley and others (1985) applied a combination of the techniques used by Seed and others (1983) and Youd and Perkins (1978) for their mapping of liquefaction hazards in the Los Angeles region. This method combines geotechnical analyses, geologic and hydrologic mapping, and probabilistic earthquake shaking estimates, but follows criteria adopted by the State Mining and Geology Board (DOC, 2000).

LIQUEFACTION SUSCEPTIBILITY

Liquefaction susceptibility reflects the relative resistance of a soil to loss of strength when subjected to ground shaking. Physical properties of soil such as sediment grain-size distribution, compaction, cementation, saturation, and depth govern the degree of resistance to liquefaction. Some of these properties can be correlated to a sediment's geologic age and environment of deposition. With increasing age, relative density may increase through cementation of the particles or compaction caused by the weight of the overlying sediment. Grain-size characteristics of a soil also influence susceptibility to liquefaction. Sand is more susceptible than silt or gravel, although silt of low plasticity is treated as liquefiable in this investigation. Cohesive soils generally are not considered susceptible to liquefaction. Such soils may be vulnerable to strength loss with remolding and represent a hazard that is not addressed in this investigation. Soil characteristics and processes that result in higher measured penetration resistances generally indicate lower liquefaction susceptibility. Thus, blow count and cone penetrometer values are useful indicators of liquefaction susceptibility.

Saturation is required for liquefaction, and the liquefaction susceptibility of a soil varies with the depth to ground water. Very shallow ground water increases the susceptibility to liquefaction (soil is more likely to liquefy). Soils that lack resistance (susceptible soils) typically are saturated, loose and sandy. Soils resistant to liquefaction include all soil types that are dry, cohesive, or sufficiently dense.

DMG's map inventory of areas containing soils susceptible to liquefaction begins with evaluation of geologic maps and historical occurrences, cross-sections, geotechnical test data, geomorphology, and ground-water hydrology. Soil properties and soil conditions such as type, age, texture, color, and consistency, along with historical depths to ground water are used to identify, characterize, and correlate susceptible soils. Because Quaternary geologic mapping is based on similar soil observations, liquefaction susceptibility maps typically are similar to Quaternary geologic maps. DMG's qualitative relations between susceptibility, geologic map unit and depth to ground water is summarized in Table 1.3.

Most Holocene materials within the quadrangle have susceptibility assignments of high (H) to very high (VH) where water levels are within 30 feet of the ground surface (Table 1.3). This differs from Geomatrix (1992) susceptibility assignments. Geomatrix (1992) mapped Holocene alluvial fan deposits having water table depths within 30 feet of the ground surface as having low susceptibility. This difference in susceptibility mapping is evident in dissimilar zone lines in the southwestern corner of the quadrangle. Undifferentiated Holocene alluvium (Qha) has been assigned a moderate susceptibility based on the relative age and fine-grained composition of the deposit in this area. Latest Pleistocene to Holocene stream terrace deposits (Qt) and undifferentiated late Pleistocene to Holocene alluvium (Qa) have moderate susceptibility assignments where water levels are within 10 feet of the ground surface. Undifferentiated latest Pleistocene alluvium

(Qpa) and undifferentiated early to latest Pleistocene alluvium (Qoa) in the upland valleys within the foothills have low (L) susceptibility assignments where water levels are within 30 feet of the ground surface.

LIQUEFACTION OPPORTUNITY

Liquefaction opportunity is a measure, expressed in probabilistic terms, of the potential for strong ground shaking. Analyses of in-situ liquefaction resistance require assessment of liquefaction opportunity. The minimum level of seismic excitation to be used for such purposes is the level of peak ground acceleration (PGA) with a 10% probability of exceedance over a 50-year period (DOC, 2000). The earthquake magnitude used in DMG's analysis is the magnitude that contributes most to the calculated PGA for an area.

For the Calaveras Reservoir Quadrangle, PGA's of 0.69g to 0.87g, resulting from earthquakes of moment magnitudes 6.4 to 7.1 were used for liquefaction analyses. The PGA and magnitude values were based on de-aggregation of the probabilistic hazard at the 10% in 50-year hazard level (Petersen and others, 1996). See the ground motion portion (Section 3) of this report for further details.

Quantitative Liquefaction Analysis

DMG performs quantitative analysis of geotechnical data to evaluate liquefaction potential using the Seed-Idriss Simplified Procedure (Seed and Idriss, 1971; Seed and others, 1983; National Research Council, 1985; Seed and others, 1985; Seed and Harder, 1990; Youd and Idriss, 1997). Using the Seed-Idriss Simplified Procedure one can calculate soil resistance to liquefaction, expressed in terms of cyclic resistance ratio (CRR), based on SPT results, ground-water level, soil density, moisture content, soil type, and sample depth. CRR values are then compared to calculated earthquake-generated shear stresses expressed in terms of cyclic stress ratio (CSR). The Seed-Idriss Simplified Procedure requires normalizing earthquake loading relative to a M7.5 event for the liquefaction analysis. To accomplish this, DMG's analysis uses the Idriss magnitude scaling factor (MSF) (Youd and Idriss, 1997). It is convenient to think in terms of a factor of safety (FS) relative to liquefaction, where: FS = (CRR / CSR) * MSF. FS, therefore, is a quantitative measure of liquefaction potential. DMG uses a factor of safety of 1.0 or less, where CSR equals or exceeds CRR, to indicate the presence of potentially liquefiable soil. While an FS of 1.0 is considered the "trigger" for liquefaction, for a site specific analysis an FS of as much as 1.5 may be appropriate depending on the vulnerability of the site and related structures. The DMG liquefaction analysis program calculates an FS for each geotechnical sample for which blow counts were collected. Typically, multiple samples are collected for each borehole. The lowest FS in each borehole is used for that location. FS values vary in reliability according to the quality of the geotechnical data used in their calculation. FS, as well as other considerations such as slope, presence of free faces, and thickness and depth of potentially liquefiable soil, are evaluated in order to construct liquefaction potential maps, which are then used to make a map showing zones of required investigation.

Of the 16 geotechnical borehole logs reviewed in this study (Plate 1.2), 13 include blow-count data from SPT's or from penetration tests that allow reasonable blow count translations to SPT-equivalent values. Non-SPT values, such as those resulting from the use of 2-inch or 2 $^{1}/_{2}$-inch inside-diameter ring samplers, were translated to SPT-equivalent values if reasonable factors could be used in conversion calculations. The reliability of the SPT-equivalent values varies. Therefore, they are weighted and used in a more qualitative manner. Few borehole logs, however, include all the information (for example: soil density, moisture content, sieve analysis, etc.) required for an ideal Simplified Seed Procedure. For boreholes having acceptable penetration tests, liquefaction analysis is performed using recorded density, moisture, and sieve test values or using average test values of similar materials.

The liquefaction evaluation procedures used in the Simplified Seed Procedure were developed primarily for clean sand and silty sand. As described above, results depend greatly on accurate evaluation of in-situ soil density as measured by the number of soil penetration blow counts (N) using an SPT sampler. However, many of the Holocene alluvial deposits in the study area contain a significant gravel content. In the past, gravelly soils were considered not to be susceptible to liquefaction because the high permeability of these soils would allow the dissipation of pore pressures before liquefaction could occur. However, liquefaction in gravelly soils has been observed during earthquakes and recent laboratory studies have shown that some gravelly soils are susceptible to liquefaction (Ishihara, 1985; Harder and Seed, 1986; Budiman and Mohammadi, 1995; Evans and Zhou, 1995; and Sy and others, 1995). SPT-derived density measurements in gravelly soils are unreliable and generally too high. These tests are likely to lead to overestimation of the density of the soil and, therefore, result in an underestimation of the liquefaction susceptibility. To identify potentially liquefiable units where the N values appear to have been affected by gravel content, correlations were made with boreholes in the same unit where the N values do not appear to have been affected by gravel content.

LIQUEFACTION ZONES

Criteria for Zoning

Areas underlain by materials susceptible to liquefaction during an earthquake were included in liquefaction zones using criteria developed by the Seismic Hazards Mapping Act Advisory Committee and adopted by the California State Mining and Geology Board (DOC, 2000). Under those guideline criteria, liquefaction zones are areas meeting one or more of the following:

1. Areas known to have experienced liquefaction during historical earthquakes

2. All areas of uncompacted artificial fill containing liquefaction-susceptible material that are saturated, nearly saturated, or may be expected to become saturated

3. Areas where sufficient existing geotechnical data and analyses indicate that the soils are potentially liquefiable

4. Areas where existing geotechnical data are insufficient

In areas of limited or no geotechnical data, susceptibility zones may be identified by geologic criteria as follows:

a) Areas containing soil deposits of late Holocene age (current river channels and their historic floodplains, marshes and estuaries), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.10 g and the water table is less than 40 feet below the ground surface; or

b) Areas containing soil deposits of Holocene age (less than 11,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.20 g and the historical high water table is less than or equal to 30 feet below the ground surface; or

c) Areas containing soil deposits of latest Pleistocene age (11,000 to 15,000 years), where the M7.5-weighted peak acceleration that has a 10% probability of being exceeded in 50 years is greater than or equal to 0.30 g and the historical high water table is less than or equal to 20 feet below the ground surface.

Application of SMGB criteria to liquefaction zoning in the Calaveras Reservoir Quadrangle is summarized below.

Areas of Past Liquefaction

Tinsley and others (1998) compiled observations of evidence for liquefaction for the 1989 Loma Prieta earthquake, and Youd and Hoose (1978) for the 1868 Hayward and 1906 San Andreas earthquakes. Knudsen and others (2000) developed a digital compilation of these two previous sources. This digital database differs from earlier compilation efforts in that the observations are plotted on a 1:24,000 scale base map versus the smaller-scale base maps used in the earlier publications. Site locations were reevaluated and single sites were sometimes broken into two or more where the greater base map detail allowed.

Within the Calaveras Reservoir Quadrangle, Youd and Hoose (1978) record one potential historical liquefaction event (Plate 1.2). In 1906, reports of ground fractures developing on the road between Calaveras Valley and the mouth of Alum Rock Canyon developed possibly as a result of lateral spreading or settlement. Also in 1906, along Penitencia Creek Road, a “considerable amount of debris had slid into the road” as a result of shallow slump failures.

Artificial Fills

In the Calaveras Reservoir Quadrangle, areas of artificial fill large enough to show at the scale of the mapping consist of fill for the Calaveras Reservoir and Cherry Flat Reservoir dams. Since these fills are considered to be properly engineered, zoning for liquefaction in such areas depends on soil conditions in underlying strata.

Areas with Sufficient Existing Geotechnical Data

Borehole logs that include penetration test data and reasonably sufficient lithologic descriptions were used to evaluate liquefaction potential. These areas with sufficient geotechnical data are evaluated for zoning based on the liquefaction potential determined by the Simplified Seed Procedure. The Holocene alluvial fan deposits (Qhf) that cover much of Santa Clara Valley in the Calaveras Reservoir Quadrangle contain sediment layers that may liquefy under the expected earthquake loadings. However, ground water over much of the area is greater than 30 feet below the surface. Where ground-water levels are above the contact between lower density, younger materials and higher density latest Pleistocene materials these areas are included in the zone.

Areas with Insufficient Existing Geotechnical Data

Adequate geotechnical borehole information for Quaternary geologic units including modern stream channel deposits (Qhc), Holocene stream terrace deposits (Qht), undifferentiated Holocene alluvium (Qha), and undifferentiated latest Pleistocene to Holocene alluvium (Qa) generally is lacking. Soil characteristics for these units are assumed to be similar to deposits where subsurface information is available. These deposits, therefore, are included in the liquefaction zone where they meet the reasons presented in criterion 4-a, above. Conversely, latest Pleistocene to Holocene stream terrace deposits (Qt), latest Pleistocene alluvial fan deposits (Qpf), undifferentiated latest Pleistocene alluvium (Qpa), and undifferentiated early to latest Pleistocene alluvium are not included in the liquefaction zone for reasons presented in criterion 4-c, above.

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SECTION 2
EARTHQUAKE-INDUCED LANDSLIDE EVALUATION REPORT

Earthquake-Induced Landslide Zones in the Calaveras Reservoir 7.5-Minute Quadrangle, Santa Clara County, California

By
Mark O. Wiegers, Kent Aue, and Timothy P. McCrink

California Department of Conservation
Division of Mines and Geology

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use seismic hazard zone maps prepared by DMG in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.conservation.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes seismic hazard zone mapping for earthquake-induced landslides in the Calaveras Reservoir 7.5-minute Quadrangle. This section, along with Section 1 addressing liquefaction, and Section 3 addressing earthquake shaking, form a report that is one of a series that summarizes the preparation of seismic hazard zone maps within the state (Smith, 1996). Additional information on seismic hazard zone mapping in California can be accessed on DMG's Internet web page: http://www.conservation.ca.gov/dmg/shezp/.

BACKGROUND

Landslides triggered by earthquakes historically have been a significant cause of earthquake damage. In California, large earthquakes such as the 1971 San Fernando, 1989 Loma Prieta, and 1994 Northridge earthquakes triggered landslides that were responsible for destroying or damaging numerous structures, blocking major transportation corridors, and damaging life-line infrastructure. Areas that are most susceptible to earthquake-induced landslides are steep slopes in poorly cemented or highly fractured rocks, areas underlain by loose, weak soils, and areas on or adjacent to existing landslide deposits. These geologic and terrain conditions exist in many parts of California, including numerous hillside areas that have already been developed or are likely to be developed in the future. The opportunity for strong earthquake ground shaking is high in many parts of California because of the presence of numerous active faults. The combination of these factors constitutes a significant seismic hazard throughout much of California, including the hillside areas of the Calaveras Reservoir Quadrangle.

METHODS SUMMARY

The mapping of earthquake-induced landslide hazard zones presented in this report is based on the best available terrain, geologic, geotechnical, and seismological data. If unavailable or significantly outdated, new forms of these data were compiled or generated specifically for this project. The following were collected or generated for this evaluation:

- Digital terrain data were used to provide an up-to-date representation of slope gradient and slope aspect in the study area

- Geologic mapping was used to provide an accurate representation of the spatial distribution of geologic materials in the study area. In addition, a map of existing landslides, whether triggered by earthquakes or not, was prepared

- Geotechnical laboratory test data were collected and statistically analyzed to quantitatively characterize the strength properties and dynamic slope stability of geologic materials in the study area

- Seismological data in the form of DMG probabilistic shaking maps and catalogs of strong-motion records were used to characterize future earthquake shaking within the mapped area

The data collected for this evaluation were processed into a series of GIS layers using commercially available software. A slope stability analysis was performed using the

Newmark method of analysis (Newmark, 1965), resulting in a map of landslide hazard potential. The earthquake-induced landslide hazard zone was derived from the landslide hazard potential map according to criteria developed in a DMG pilot study (McCrink and Real, 1996) and adopted by the State Mining and Geology Board (DOC, 2000).

SCOPE AND LIMITATIONS

The methodology used to make this map is based on earthquake ground-shaking estimates, geologic material-strength characteristics and slope gradient. These data are gathered from a variety of outside sources. Although the selection of data used in this evaluation was rigorous, the quality of the data is variable. The State of California and the Department of Conservation make no representations or warranties regarding the accuracy of the data gathered from outside sources.

Earthquake-induced landslide zone maps are intended to prompt more detailed, site-specific geotechnical investigations as required by the Act. As such, these zone maps identify areas where the potential for earthquake-induced landslides is relatively high. Due to limitations in methodology, it should be noted that these zone maps do not necessarily capture all potential earthquake-induced landslide hazards. Earthquake-induced ground failures that are not addressed by this map include those associated with ridge-top spreading and shattered ridges. It should also be noted that no attempt has been made to map potential run-out areas of triggered landslides. It is possible that such run-out areas may extend beyond the zone boundaries. The potential for ground failure resulting from liquefaction-induced lateral spreading of alluvial materials, considered by some to be a form of landsliding, is not specifically addressed by the earthquake-induced landslide zone or this report. See Section 1, Liquefaction Evaluation Report for the Calaveras Reservoir Quadrangle, for more information on the delineation of liquefaction zones.

The remainder of this report describes in more detail the mapping data and processes used to prepare the earthquake-induced landslide zone map for the Calaveras Reservoir Quadrangle. The information is presented in two parts. Part I covers physiographic, geologic and engineering geologic conditions in the study area. Part II covers the preparation of landslide hazard potential and landslide zone maps.

PART I

PHYSIOGRAPHY

Study Area Location and Physiography

The Calaveras Reservoir 7.5-minute Quadrangle includes approximately 60 square miles of land in Alameda and Santa Clara counties, along the southeastern margin of San Francisco Bay. The boundary between Alameda and Santa Clara counties trends east-west through the northern portion of the quadrangle. Approximately 8 square miles (13 percent of the quadrangle) along the northern boundary of the quadrangle is within Alameda County. This evaluation report, and accompanying Seismic Hazard Map cover only that portion of the quadrangle that is within Santa Clara County.

The map includes parts of the City of San Jose and the City of Milpitas as well as unincorporated Santa Clara County land. In addition, approximately 13,000 acres of watershed lands that are owned and managed by the City of San Francisco also lie within the quadrangle. Calaveras Reservoir, owned by the City of San Francisco, lies within the north-central part of the quadrangle. A small reservoir, Cherry Flat Reservoir, which is owned by the City of San Jose, is in the southeastern corner of the map area.

Most of the area is steeply sloping terrain on the southwestern flank of the Diablo Range. The uplands border the gently sloping floor of a part of the Santa Clara Valley, which extends into the southwestern corner of the map area. Elevations in the area range from slightly less than 100 feet above sea level on the valley floor in the southwestern corner to more than 2500 feet above sea level in the eastern part of the quadrangle.

The hillside portions of the map area in the Diablo Range are characterized by northwest–trending ridges with deeply incised streams. Calaveras Creek flows to the northwest across the east-central part of the map area. It is impounded behind Calaveras Dam near the north edge of the area in Alameda County. Calaveras Reservoir sits in Calaveras Valley. Arroyo Hondo is a deeply incised tributary that flows into the east side of Calaveras Reservoir. Several deeply incised streams, including Penetentia Creek and Berryessa Creek, also drain the southwestern side of the hills and flow onto the floor of Santa Clara Valley.

Most of the urbanized areas in the quadrangle lie on the floor of the Santa Clara Valley in the southwestern part of the quadrangle. Interstate 680 extends across the valley floor in this area. Several significant residential developments extend into the lower foothills also in the southwestern part of the map area. The rest of the map area is sparsely developed. Paved county roads extend into some of the rural areas. Watershed lands surrounding Calaveras Reservoir are accessed primarily by unpaved roads.

Digital Terrain Data

The calculation of slope gradient is an essential part of the evaluation of slope stability under earthquake conditions. An accurate slope gradient calculation begins with an up-to-date map representation of the earth's surface. Within the Calaveras Reservoir Quadrangle, a Level 2 digital elevation model (DEM) was obtained from the USGS (U.S. Geological Survey, 1993). This DEM, which was prepared from the 7.5-minute quadrangle topographic contours based on 1960 aerial photography, has a 10-meter horizontal resolution and a 7.5-meter vertical accuracy.

Areas that have undergone large-scale grading since 1960 in the hilly portions of the quadrangle were updated to reflect the new topography. Terrain data reflecting this recent grading, in the form of digital contours, was obtained from the City of Milpitas. The original data was derived from low altitude photography flown in 1995. The contour data were converted into a DEM format and merged with the USGS DEM. The new DEM data covers only a portion of the hilly areas of the Calaveras Reservoir Quadrangle. This DEM data extends from Berryessa Creek on the south to Calera Creek on the north, and from the Spring Valley Golf Club on the east to the western edge of the quadrangle. The portion of the quadrangle that uses the City of Milpitas terrain data is shown on Plate 2.1.

A slope map was made from the DEM using a third-order, finite difference, center-weighted algorithm (Horn, 1981). The DEM was also used to make a slope aspect map. The manner in which the slope and aspect maps were used to prepare the zone map will be described in subsequent sections of this report.

GEOLOGY

Bedrock and Surficial Geology

The primary source of bedrock geologic mapping used in this slope stability evaluation was the digital database "Preliminary Geologic Map of the San Jose 30 x 60 minute Quadrangle" prepared by the U.S. Geological Survey (Wentworth and others, 1999). The 1:24,000-scale geology of the Calaveras Reservoir 7.5-minute Quadrangle was obtained from this database. The surficial geologic mapping for the Calaveras Reservoir Quadrangle was prepared by Knudsen and others (2000) at a scale of 1:24,000. Surficial geology is discussed in detail in Section 1 of this report.

DMG geologists merged the surficial and bedrock geologic map databases and contacts between surficial and bedrock units were modified in some areas to resolve differences between the two maps. Geologic reconnaissance was performed to assist in adjusting contacts and to review the lithology of geologic units and geologic structure.

The bedrock sequences in the 30 x 60-minute San Jose Quadrangle have been divided into eight individual fault-bounded structural blocks based on differing stratigraphic sequences and geologic history (Wentworth and others, 1999). Two of these structural blocks, the Alum Rock Block and the Mt. Hamilton Block, extend into the Calaveras Reservoir 7.5-minute Quadrangle. These blocks are separated by the northwest-trending Calaveras Fault. The Alum Rock Block is on the southwestern side of the fault. The Mt. Hamilton Block is on the northeastern side. The following descriptions of bedrock units in these blocks are based primarily on the work of Wentworth and others (1999), and are supplemented by observations made during field reconnaissance by DMG geologists.

Alum Rock Block

The Alum Rock Block consists of Jurassic through Quaternary strata that were deposited on the Jurassic Coast Range Ophiolite and associated intermediate and silicic volcanic rocks. Jurassic and Cretaceous Franciscan Complex rocks occur as small fault-bounded slivers within the Alum Rock Block. Middle Miocene rocks overlie the Jurassic and Cretaceous rocks. No rocks of lower Tertiary age are present. The sequence is cut by a series of transpressional faults that displace units as young as Holocene.

The Jurassic Coast Range Ophiolite (Jsp) and associated intermediate and silicic volcanic rocks (Jbk) are the oldest rocks in the Alum Rock Block. The Coast Range Ophiolite consists of sheared serpentinite with some massive serpentinized harzburgite. Associated volcanic rocks in the study area consist of highly altered keratophere and quartz keratophere. These volcanic rocks were previously mapped as the Alum Rock Rhyolite and were considered to be Tertiary on earlier maps (Dibblee, 1973; Crittenden, 1951).

A unit that is mapped (Wentworth and others, 1999) with a question mark as the Lower Cretaceous and Upper Jurassic Knoxville Formation (KJk?) is exposed in the southern part of the map area. This unit overlies the Coast Range Ophiolite and consists of dark, greenish-gray shale with thin sandstone interbeds.

The lower Tertiary (?) and Upper Cretaceous Franciscan Complex (fm) is exposed as small slivers of melange in the Alum Rock Block (Wentworth and others, 1999). It is also encountered in deep boreholes drilled through landslide deposits at a water treatment plant about 2,000 feet north of Penetentia Creek. The Franciscan melange primarily consists of intensely sheared argillite and graywacke.

Cretaceous Berryessa Formation is part of the Great Valley Sequence and is exposed on the lower flanks of the Diablo Range in the map area (Wentworth and others, 1999). It is divided into a basal conglomerate unit (Kbc) and an overlying sandstone and mudstone unit (Kbs). The conglomerate (Kbc) occurs as thick, indistinct beds with pebble, cobble, and occasional boulder clasts, intercalated with coarse-grained mica-quartz-lithic wacke. Clasts include silicic to intermediate volcanic rocks, black chert and argillite, quartz, mica schist, meta-andesite, granodiorite and granite, black hornfels, and rip-up clasts of mudstone and lithic wacke. The sandstone and mudstone unit (Kbs) consists of layers of massive, indistinctly bedded, coarse- to fine-grained, mica-quartz-lithic wacke interbedded with poorly bedded mica-bearing siltstone and claystone. Small lenses of conglomerate occur within the sandstone and mudstone unit.

An unnamed Upper Cretaceous unit (Kau) is exposed along the west side of Calaveras Reservoir. This unit contains sandstone, mudstone and conglomerate.

The Middle to Upper Miocene Claremont Formation (Tcc) is the oldest Tertiary unit in the Alum Rock Block and unconformably overlies the Mesozoic rocks (Wentworth and others, 1999). The Claremont Formation primarily consists of interbedded chert and siliceous shale. Siltstone and fine-grained quartz sandstone are present locally.

The Upper Miocene Briones Formation (Tbr) unconformably overlies the Claremont Formation. It consists of interbedded sandstone and siltstone, shell-hash conglomerate, cross-bedded sandstone, and some pebble and cobble conglomerate beds (Wentworth and others, 1999). The lower part is thin-bedded, fine-grained sandstone and shale interbedded with thick, massive sandstone beds. Indistinctly bedded conglomeratic shell beds occur in the middle part of this unit and are characteristic of this formation. The shell-rich beds typically form prominent ridges and peaks due to a resistant calcareous matrix. The upper part of the unit consists of distinctly to indistinctly bedded, massive to cross-bedded, fine- to coarse-grained sandstone.

The non-marine Upper Miocene Orinda Formation (Tor) unconformably overlies the Briones Formation. It is comprised of non-marine pebble to boulder conglomerate, conglomeratic sandstone, and coarse- to medium-grained lithic sandstone. The unit includes minor inter-layered basalt and andesite flows and sills (Torv).

The Pliocene to Pleistocene Irvington Gravels (QTi) consist of poorly to well-consolidated sand and sandy conglomerate. These deposits are exposed in the lower foothills along the margins of the Santa Clara Valley.

Unconsolidated Quaternary deposits underlie the floor of the Santa Clara Valley as well as small valleys in the hillside areas. A detailed discussion of Quaternary units can be found in Section 1.

Mount Hamilton Block

The Mount Hamilton Block forms the core of the Diablo Range and primarily consists of Franciscan rocks with scattered small bodies of serpentinite derived from the Coast Range Ophiolite (Wentworth and others, 1999). The Franciscan rocks are overlain unconformably by Miocene marine sedimentary rocks that are exposed in limited areas at the margins of the block. Miocene rocks are exposed in the study area in the vicinity of Calaveras Reservoir.

Franciscan rocks in the map area include relatively coherent blueschist-facies metagraywacke units of the Cretaceous (?) and Jurassic Yolla Bolly Terrane interleaved with Lower Tertiary (?) and Upper Cretaceous zones of melange (fm) (Wentworth and others, 1999). Melange zones include mappable blocks of greenstone (gs) and radiolarian chert (ch).

Three Yolla Bolly Terrane units are exposed in the Calaveras Reservoir Quadrangle: 1) a lower unit (fy1); 2) a middle unit (fy2); and, an undifferentiated unit (fys). These units consist of primarily metagraywacke, slaty mudstone and conglomerate and are differentiated on the basis of minor variations in cleavage and metamorphic grade. All of the units contain high-pressure, low-temperature metamorphic minerals such as pumpellyite and lawsonite. Quartz-aragonite veins are common in each of the units.

Melange zones in the map area (fm) consist of a highly sheared matrix of shale, graywacke or metagraywacke that contains an assortment of blocks and slabs of numerous rock types, including metagraywacke, argillite, chert, serpentinite, greenstone, amphibolite, tuff, eclogite, quartz schist, greenschist, basalt, marble, conglomerate, and blueschist. Individual blocks range in length from less than an inch to several hundreds of feet. Several relatively large bodies of chert (ch) and greenstone (gs) are present south of Calaveras Reservoir.

The Middle Miocene Temblor Sandstone (Tts) unconformably overlies Franciscan melange in the vicinity of Calaveras Reservoir. This unit includes fossiliferous medium- to coarse-grained sandstone, pebbly sandstone, and pebble conglomerate.

The Middle Miocene Claremont Formation (Tcc) overlies the Temblor Sandstone near the east side of Calaveras Dam. The lithology of this unit in the Mount Hamilton Block is similar to that described for the Alum Rock Block.

The bedrock units of the Mt. Hamilton Block are overlain locally by unconsolidated Quaternary alluvial deposits. A detailed discussion of Quaternary units can be found in Section 1.

Structural Geology

Mesozoic and Tertiary bedrock units in the Calaveras Reservoir Quadrangle are deformed by faults and folds. Most of the major faults and fold axes trend to the northwest. Sedimentary units generally dip moderately to steeply to the northeast and are overturned locally (Dibblee, 1972). A prominent northwest-trending syncline lies west and southwest of Calaveras Reservoir. Resistant ridge-forming beds of the Briones Formation are exposed on the limbs of this syncline. Weak landslide-prone beds of the Orinda Formation are exposed in the core of this syncline. Major faults in the study area include strike-slip and transpressive faults (Graymer, 1995). Faults with the most recent displacements are the Hayward and Calaveras faults. These faults are predominantly right-lateral strike-slip faults with active seismicity and Holocene displacement. Both of these faults have experienced historic ground rupture during large earthquakes and also experience aseismic creep displacement. Transpressional faults include the Warm Springs, Crosley and Mission Peak faults. These faults exhibit a compressional component of offset related to a transfer of slip from the Calaveras fault to the Hayward fault (Graymer, 1995). Transpressional faults cut the Plio-Peistocene Irvington Gravels and locally exhibit geomorphic evidence of late Quaternary offset (Wentworth and others, 1999).

Landslide Inventory

As a part of the geologic data compilation, an inventory of existing landslides in the Calaveras Reservoir Quadrangle was prepared by field reconnaissance, analysis of stereo-paired aerial photographs and a review of previously published landslide mapping. Landslides were mapped and digitized at a scale of 1:24,000. For each landslide included on the map a number of characteristics were compiled. These characteristics included the confidence of interpretation (definite, probable and questionable) and other properties, such as activity, thickness, and associated geologic unit(s). Landslides rated as definite and probable were carried into the slope stability analysis, and landslides rated as questionable were not carried into the slope stability analysis due to the uncertainty of their existence.

In general, landslides are abundant in the hillside areas of the Calaveras Reservoir Quadrangle. Numerous large, deep-seated bedrock landslides underlie some of the developed slopes north of Penetentia Creek. Deep-seated movements have damaged homes and other facilities in this area (Norfleet Consultants, 1995). Other deep bedrock landslides are present in other parts of the Calaveras Reservoir Quadrangle, particularly in the southeast part of the map area and on the south and east sides of Calaveras Reservoir. In addition, there are many smaller debris slides and earthflows in the map area. Landslides identified in the map area are shown on Plate 2.1. The landslides mapped for this study include both the source area and the landslide deposit.

Several units in the map area are very prone to landsliding, including the Orinda Formation and Franciscan melange. In contrast, the Briones Formation is a competent ridge former with few landslides. Some of the large, deep landslides north of Penetentia Creek involve the Irvington Gravels, however, the basal slip surface of some of these slides may have developed in bodies of serpentinite at depth (Norfleet Consultants, 1995).

The distribution of landslides mapped for this study is roughly similar to that mapped by Nilsen (1975). However, Nilsen only mapped the landslide deposits and did not include the source areas as part of the mapped landslide features. In some areas, there are some significant differences in interpretation between this inventory and that of Nilsen. This inventory includes landslides mapped by Norfleet Consultants (1995). The landslides mapped by Norfleet are within a Special Geologic Hazard Study Area established by the City of San Jose in the foothills north of Penetencia Creek. Landslides mapped for this inventory generally include landslide deposits mapped by Wentworth and others (1999), with some modifications.

ENGINEERING GEOLOGY

Geologic Material Strength

To evaluate the stability of geologic materials under earthquake conditions, the geologic map units described above were ranked and grouped on the basis of their shear strength. Generally, the primary source for rock shear-strength measurements is geotechnical reports prepared by consultants on file with local government permitting departments. Shear-strength data for the rock units identified on the Calaveras Reservoir geologic map were obtained from the City of San Jose, the County of Santa Clara, the City of Milpitas and the City of Fremont (see Appendix A). The locations of rock and soil samples taken for shear testing by consultants are shown on Plate 2.1. Shear tests from the adjacent San Jose East and Milpitas quadrangles were used to augment data for several geologic formations for which we obtained little or no shear test information in the Calaveras Reservoir Quadrangle.

Shear strength data gathered from the above sources were compiled for each geologic map unit. Geologic units were grouped on the basis of average angle of internal friction (average phi) and lithologic character. Average (mean and median) phi values for each geologic map unit and corresponding strength group are summarized in Table 2.1. For most of the geologic strength groups in the map area, a single shear strength value was assigned and used in our slope stability analysis. A geologic material strength map was made based on the groupings presented in Tables 2.1 and 2.2, and this map provides a spatial representation of material strength for use in the slope stability analysis.

The Briones Formation was subdivided further, as described below.

Adverse Bedding Conditions

Adverse bedding conditions are an important consideration in slope stability analyses. Adverse bedding conditions occur where the dip direction of bedded sedimentary rocks is roughly the same as the slope aspect, and where the dip magnitude is less than the slope gradient. Under these conditions, landslides can slip along bedding surfaces that are exposed at the ground surface due to a lack of lateral support.

To account for adverse bedding in our slope stability evaluation, we used geologic structural data in combination with digital terrain data to identify areas with potentially adverse bedding, using methods similar to those of Brabb (1983). The structural data, derived from the geologic map database, was used to categorize areas of common bedding dip direction and magnitude. The dip direction was then compared to the slope aspect and, if the same, the dip magnitude and slope gradient categories were compared. If the dip magnitude was less than or equal to the slope gradient category but greater than 25% (4:1 slope), the area was marked as a potential adverse bedding area.

The Briones Formation, which contains interbedded sandstone and shale, was subdivided based on shear strength differences between coarse-grained (higher strength) and fine-grained (lower strength) rocks. Shear strength values for the fine- and coarse-grained rocks were then applied to areas of favorable and adverse bedding orientation, which were determined from structural and terrain data as discussed above. It was assumed that coarse-grained material (higher strength) dominates where bedding dips into a slope (favorable bedding) while fine-grained (lower strength) material dominates where bedding dips out of a slope (adverse bedding). The geologic material strength map was modified by assigning the lower, fine-grained shear strength values to areas where potential adverse bedding conditions were identified. The favorable and adverse bedding shear strength parameters for the Briones Formation is included in Table 2.1.

Existing Landslides

The strength characteristics of existing landslides (Qls) must be based on tests of the materials along the landslide slip surface. Ideally, shear tests of slip surfaces formed in each mapped geologic unit would be used. However, this amount information is rarely available, and for the preparation of the earthquake-induced landslide zone map it has been assumed that all landslides within the quadrangle have the same slip surface strength parameters. We collect and use primarily “residual” strength parameters from laboratory tests of slip surface materials tested in direct shear or ring shear test equipment. Back-calculated strength parameters, if the calculations appear to have been performed appropriately, also have been used. For the Calaveras Reservoir Quadrangle the phi value used in the analysis was based on a single measured residual shear strength along the slip surface of a large bedrock landslide at the Penetentia Creek Water Treatment Plant, located just north of Penetentia Creek. This shear test information is included in Table 2.1.

CALAVERAS RESERVOIR QUADRANGLE
SHEAR STRENGTH GROUPS

	Formation Name	Number Tests	Mean/Median Phi (deg)	Mean/Median Group Phi (deg)	Mean/Median Group C (psf)	No Data: Similar Lithology	Phi Values Used in Stability Analyses
GROUP 1	Tbr(fbc)	5	37/32	37/32	807/278		37
GROUP 2	KJk	5	33/41	27/32	873/750	Kau	32
	Tbr(abc)	9	30/32			Tts	
GROUP 3	Jsp	14	27/27	27/27	664/650	bl	27
						ch	
						fy1	
						fy2	
						fys	
						gs	
GROUP 4	fm	20	21/21	21/20	857/800	ac	21
	Jbk	20	24/22			af	
	Kbc	33	21/18				
	Tcc	19	22/20				
	QTi	112	21/19				
	Q*	37	22/21				
GROUP 5	Tor	24	19/17	19/17	1040/970	Torv	17
GROUP 6	Qls	1	12		745		12

abc = adverse bedding condition, fine-grained material strength
fbc = favorable bedding condition, coarse-grained material strength
Q* = all mapped Quaternary units

Formations for strength groups from Wentworth, 1999
except Qls which is from landslide inventory prepared
for this study

Table 2.1. Summary of Shear-Strength Statistics for the Calaveras Reservoir Quadrangle.

SHEAR-STRENGTH GROUPS FOR THE CALAVERAS RESERVOIR 7.5-MINUTE QUADRANGLE

GROUP 1	GROUP 2	GROUP 3	GROUP 4	GROUP 5	GROUP 6
Tbr(fbc)	Tbr(abc)	Jsp	fm	Tor	Qls
	KJk	bl	Jbk	Torv	
	Kau	ch	Kbc		
	Tts	fy1	Kbs		
		fy2	Tcc		
		fys	QTi		
		gs	Q*		
			ac		

Q* = all Quaternary units

Table 2.2. Summary of Shear-Strength Groups for the Calaveras Reservoir Quadrangle.

PART II

EARTHQUAKE-INDUCED LANDSLIDE HAZARD POTENTIAL

Design Strong-Motion Record

To evaluate earthquake-induced landslide hazard potential in the study area, a method of dynamic slope stability analysis developed by Newmark (1965) was used. The Newmark method analyzes dynamic slope stability by calculating the cumulative down-slope displacement for a given earthquake strong-motion time history. As implemented for the preparation of earthquake-induced landslide zones, the Newmark method necessitates the selection of a design earthquake strong-motion record to provide the “ground shaking opportunity.” For the Calaveras Reservoir Quadrangle, selection of a strong motion record was based on an estimation of probabilistic ground motion parameters for modal magnitude, modal distance, and peak ground acceleration (PGA). The parameters were estimated from maps prepared by DMG for a 10% probability of being exceeded in 50 years (Petersen and others, 1996). The parameters used in the record selection are:

Modal Magnitude:	6.6 – 7.2
Modal Distance:	2.8 – 10.2 km
PGA:	0.66 – 1.02g

The strong-motion record selected for the slope stability analysis in the Calaveras Reservoir Quadrangle is the Corralitos record from the magnitude 6.9 (M_w) 1989 Loma Prieta earthquake (Shakal and others, 1989). This record had a source to recording site distance of 5.1 km and a peak ground acceleration (PGA) of 0.64. The selected strong-motion record was not scaled or otherwise modified prior to its use in the analysis.

Displacement Calculation

The design strong-motion record was used to develop a relationship between landslide displacement and yield acceleration (a_y), defined as the earthquake horizontal ground acceleration above which landslide displacements take place. This relationship was prepared by integrating the design strong-motion record twice for a given acceleration value to find the corresponding displacement, and the process was repeated for a range of acceleration values (Jibson, 1993). The resulting curve in Figure 2.1 represents the full spectrum of displacements that can be expected for the design strong-motion record. This curve provides the required link between anticipated earthquake shaking and estimates of displacement for different combinations of geologic materials and slope gradient, as described in the Slope Stability Analysis section below.

The amount of displacement predicted by the Newmark analysis provides an indication of the relative amount of damage that could be caused by earthquake-induced landsliding. Displacements of 30, 15 and 5 cm were used as criteria for rating levels of earthquake-induced landslide hazard potential based on the work of Youd (1980), Wilson and Keefer (1983), and a DMG pilot study for earthquake-induced landslides (McCrink and Real, 1996). Applied to the curve in Figure 2.1, these displacements correspond to yield accelerations of 0.086, 0.133 and 0.234g. Because these yield acceleration values are derived from the design strong-motion record, they represent the ground shaking opportunity thresholds that are significant in the Calaveras Reservoir Quadrangle.

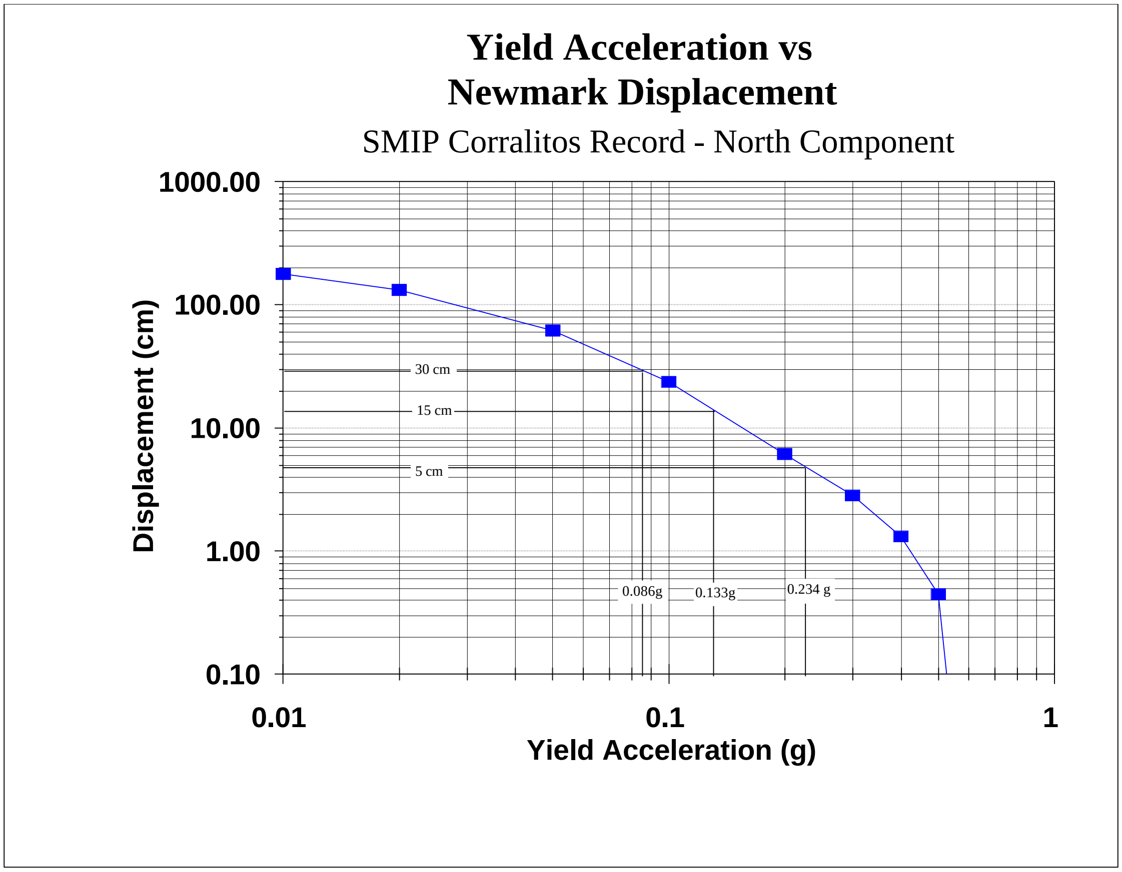

Figure 2.1. Yield Acceleration vs. Newmark Displacement for the 1989 Loma Prieta Earthquake Corralitos Record. Record from California Strong Motion Instrumentation Program (CSMIP) Station 57007.

Slope Stability Analysis

A slope stability analysis was performed for each geologic material strength group at slope increments of 1 degree. An infinite-slope failure model under unsaturated slope conditions was assumed. A factor of safety was calculated first, followed by the calculation of yield acceleration from Newmark's equation:

$$a_y = (FS - 1)g \sin \alpha$$

where FS is the Factor of Safety, g is the acceleration due to gravity, and α is the direction of movement of the slide mass, in degrees measured from the horizontal, when displacement is initiated (Newmark, 1965). For an infinite slope failure α is the same as the slope angle.

The yield accelerations resulting from Newmark's equations represent the susceptibility to earthquake-induced failure of each geologic material strength group for a range of slope gradients. Based on the relationship between yield acceleration and Newmark displacement shown in Figure 2.1, hazard potentials were assigned as follows:

1. If the calculated yield acceleration was less than 0.086g, Newmark displacement greater than 30 cm is indicated, and a HIGH hazard potential was assigned (H on Table 2.3)

2. If the calculated yield acceleration fell between 0.086g and 0.133g, Newmark displacement between 15 cm and 30 cm is indicated, and a MODERATE hazard potential was assigned (M on Table 2.3)

3. If the calculated yield acceleration fell between 0.133g and 0.234g, Newmark displacement between 5 cm and 15 cm is indicated, and a LOW hazard potential was assigned (L on Table 2.3)

4. If the calculated yield acceleration was greater than 0.234g, Newmark displacement of less than 5 cm is indicated, and a VERY LOW potential was assigned (VL on Table 2.3)

Table 2.3 summarizes the results of the stability analyses. The earthquake-induced landslide hazard potential map was prepared by combining the geologic material-strength map and the slope map according to this table.

				CALAVERAS RESERVOIR QUADRANGLE						
				HAZARD POTENTIAL MATRIX						
					SLOPE CATEGORY (% SLOPE)					
GEOLOGIC										
STRENGTH	MEAN	I	II	III	IV	V	VI	VII	VIII	IX
GROUP	PHI	0 to 9%	9 to 15%	15 to 27%	27 to 38%	38 to 42%	42 to 50%	50 to 60%	60 to 67%	>67%
1	37	VL	VL	VL	VL	VL	VL	L	M	H
2	32	VL	VL	VL	VL	L	L	M	H	H
3	27	VL	VL	VL	L	M	H	H	H	H
4	21	VL	VL	L	M	H	H	H	H	H
5	17	VL	L	M	H	H	H	H	H	H
6	12	L	H	H	H	H	H	H	H	H

Table 2.3. Hazard Potential Matrix for Earthquake-Induced Landslides in the Calaveras Reservoir Quadrangle. Shaded area indicates hazard potential levels included within the zone of required investigation. H = High, M = Moderate, L = Low, VL = Very Low.

EARTHQUAKE-INDUCED LANDSLIDE HAZARD ZONE

Criteria for Zoning

Earthquake-induced landslide zones were delineated using criteria adopted by the California State Mining and Geology Board (DOC, 2000). Under these criteria, earthquake-induced landslide hazard zones are defined as areas that meet one or both of the following conditions:

1. Areas that have been identified as having experienced landslide movement in the past, including all mappable landslide deposits and source areas as well as any landslide that is known to have been triggered by historic earthquake activity.

2. Areas where the geologic and geotechnical data and analyses indicate that the earth materials may be susceptible to earthquake-induced slope failure.

These conditions are discussed in further detail in the following sections.

Existing Landslides

Existing landslides typically consist of disrupted soils and rock materials that are generally weaker than adjacent undisturbed rock and soil materials. Previous studies indicate that existing landslides can be reactivated by earthquake movements (Keefer, 1984). Earthquake-triggered movement of existing landslides is most pronounced in steep head scarp areas and at the toe of existing landslide deposits. Although reactivation of deep-seated landslide deposits is less common (Keefer, 1984), a significant number of deep-seated landslide movements have occurred during, or soon after, several recent earthquakes. Based on these observations, all existing landslides with a definite or probable confidence rating are included within the earthquake-induced landslide hazard zone.

Geologic and Geotechnical Analysis

Based on the conclusions of a pilot study performed by DMG (McCrink and Real, 1996), it has been concluded that earthquake-induced landslide hazard zones should encompass all areas that have a High, Moderate or Low level of hazard potential (see Table 2.3). This would include all areas where the analyses indicate earthquake displacements of 5 centimeters or greater. Areas with a Very Low hazard potential, indicating less than 5 centimeters displacement, are excluded from the zone.

As summarized in Table 2.3, all areas characterized by the following geologic strength group and slope gradient conditions are included in the earthquake-induced landslide hazard zone:

1. Geologic Strength Group 6 is included for all slope gradient categories. (Note: Geologic Strength Group 6 includes all mappable landslides with a definite or probable confidence rating)

2. Geologic Strength Group 5 is included for all slopes steeper than 9 percent

3. Geologic Strength Group 4 is included for all slopes steeper than 15 percent

4. Geologic Strength Group 3 is included for all slopes steeper than 27 percent

5. Geologic Strength Group 2 is included for all slopes greater than 38 percent

6. Geologic Strength Group 1 is included for all slopes greater than 50 percent

This results in 56.5 % of the Santa Clara County land in the Calaveras Reservoir Quadrangle lying within the earthquake-induced landslide hazard zone.

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AIR PHOTOS

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APPENDIX A
SOURCE OF ROCK STRENGTH DATA

SOURCE*	NUMBER OF TESTS SELECTED
City of San Jose	173
Santa Clara County	24
City of Milpitas	78
City of Fremont	24
Total Number of Shear Tests	299

*Note: Shear test data from adjoining San Jose East, Milpitas and Niles quadrangles used for some units for which we obtained little or no shear test data in the Calaveras Reservoir Quadrangle.

SECTION 3
GROUND SHAKING EVALUATION REPORT

Potential Ground Shaking in the Calaveras Reservoir 7.5-Minute Quadrangle, Santa Clara County, California

By

Mark D. Petersen*, Chris H. Cramer*, Geoffrey A. Faneros, Charles R. Real, and Michael S. Reichle

California Department of Conservation
Division of Mines and Geology
***Formerly with DMG, now with U.S. Geological Survey**

PURPOSE

The Seismic Hazards Mapping Act (the Act) of 1990 (Public Resources Code, Chapter 7.8, Division 2) directs the California Department of Conservation (DOC), Division of Mines and Geology (DMG) to delineate Seismic Hazard Zones. The purpose of the Act is to reduce the threat to public health and safety and to minimize the loss of life and property by identifying and mitigating seismic hazards. Cities, counties, and state agencies are directed to use the Seismic Hazard Zone Maps in their land-use planning and permitting processes. The Act requires that site-specific geotechnical investigations be performed prior to permitting most urban development projects within the hazard zones. Evaluation and mitigation of seismic hazards are to be conducted under guidelines established by the California State Mining and Geology Board (DOC, 1997; also available on the Internet at http://www.conservation.ca.gov/dmg/pubs/sp/117/).

This section of the evaluation report summarizes the ground motions used to evaluate liquefaction and earthquake-induced landslide potential for zoning purposes. Included are ground motion and related maps, a brief overview on how these maps were prepared, precautionary notes concerning their use, and related references. The maps provided herein are presented at a scale of approximately 1:150,000 (scale bar provided on maps), and show the full 7.5-minute quadrangle and portions of the adjacent eight quadrangles. They can be used to assist in the specification of earthquake loading conditions ***for the analysis of ground failure*** according to the “Simple Prescribed Parameter Value” method (SPPV) described in the site investigation guidelines (California Department of Conservation, 1997). Alternatively, they can be used as a basis for comparing levels of ground motion determined by other methods with the statewide standard.

This section and Sections 1 and 2 (addressing liquefaction and earthquake-induced landslide hazards) constitute a report series that summarizes development of seismic hazard zone maps in the state. Additional information on seismic hazard zone mapping in California can be accessed on DMG’s Internet homepage: http://www.conservation.ca.gov/dmg/shezp/

EARTHQUAKE HAZARD MODEL

The estimated ground shaking is derived from the statewide probabilistic seismic hazard evaluation released cooperatively by the California Department of Conservation, Division of Mines and Geology, and the U.S. Geological Survey (Petersen and others, 1996). That report documents an extensive 3-year effort to obtain consensus within the scientific community regarding fault parameters that characterize the seismic hazard in California. Fault sources included in the model were evaluated for long-term slip rate, maximum earthquake magnitude, and rupture geometry. These fault parameters, along with historical seismicity, were used to estimate return times of moderate to large earthquakes that contribute to the hazard.

The ground shaking levels are estimated for each of the sources included in the seismic source model using attenuation relations that relate earthquake shaking with magnitude, distance from the earthquake, and type of fault rupture (strike-slip, reverse, normal, or subduction). The published hazard evaluation of Petersen and others (1996) only considers uniform firm-rock site conditions. In this report, however, we extend the hazard analysis to include the hazard of exceeding peak horizontal ground acceleration (PGA) at 10% probability of exceedance in 50 years on spatially uniform conditions of rock, soft rock, and alluvium. These soil and rock conditions approximately correspond to site categories defined in Chapter 16 of the Uniform Building Code (ICBO, 1997), which are commonly found in California. We use the attenuation relations of Boore and others (1997), Campbell (1997), Sadigh and others (1997), and Youngs and others (1997) to calculate the ground motions.

The seismic hazard maps for ground shaking are produced by calculating the hazard at sites separated by about 5 km. Figures 3.1 through 3.3 show the hazard for PGA at 10% probability of exceedance in 50 years assuming the entire map area is firm rock, soft rock, or alluvial site conditions respectively. The sites where the hazard is calculated are represented as dots and ground motion contours as shaded regions. The quadrangle of interest is outlined by bold lines and centered on the map. Portions of the eight adjacent

CALAVERAS RESERVOIR 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

FIRM ROCK CONDITIONS

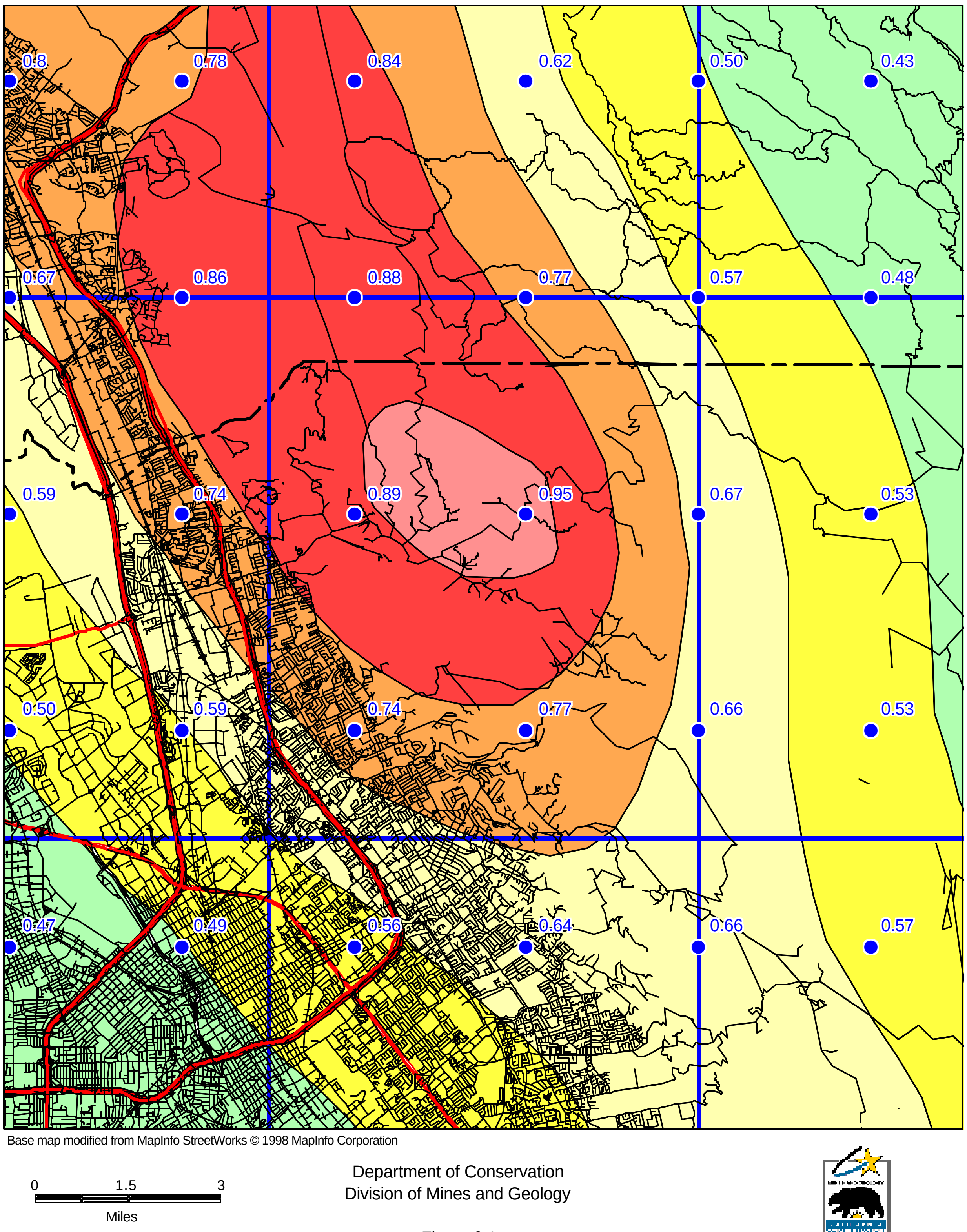

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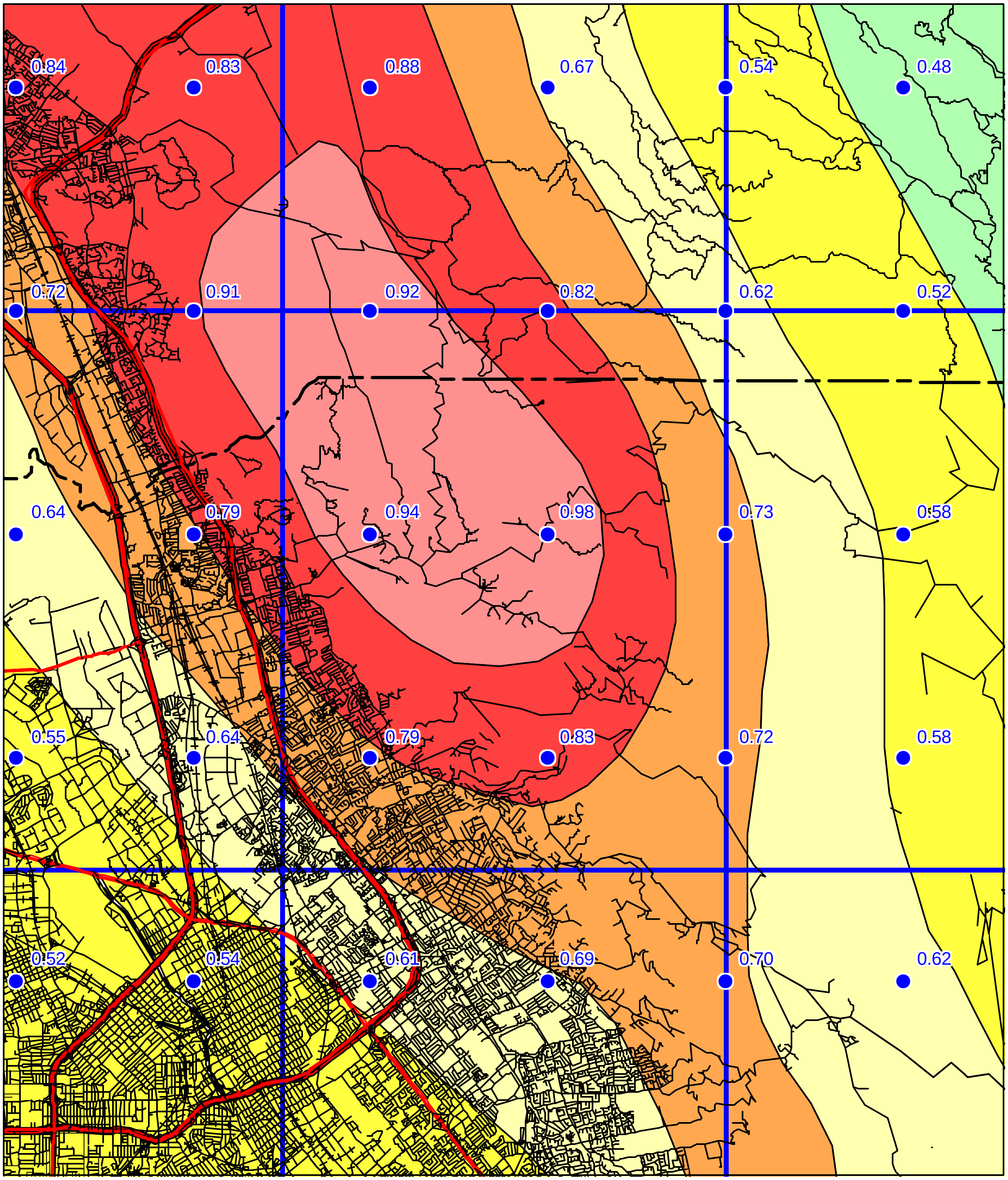
Figure 3.1

CALAVERAS RESERVOIR 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

SOFT ROCK CONDITIONS



Base map modified from MapInfo StreetWorks © 1998 MapInfo Corporation

0 1.5 3
Miles

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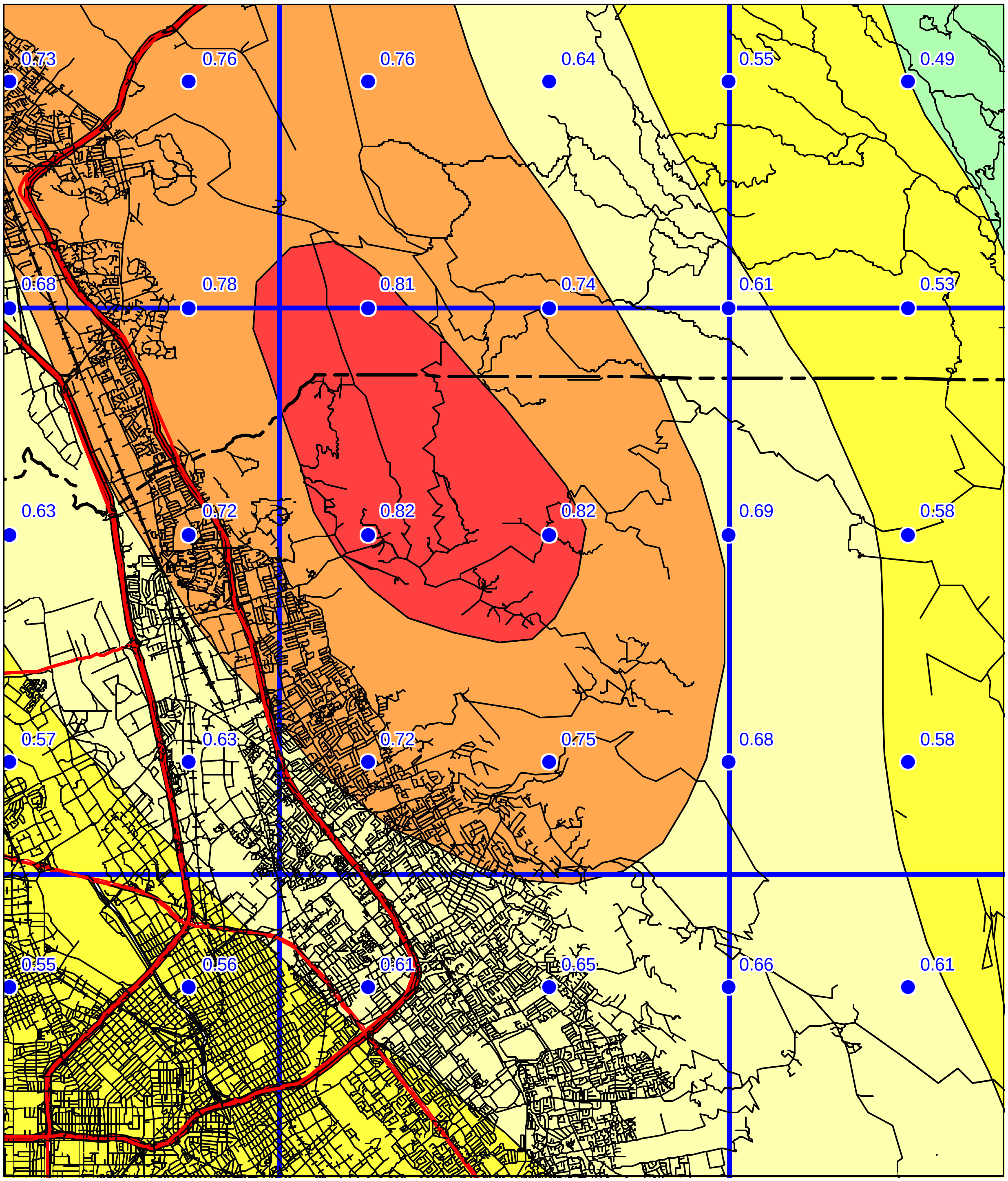
Figure 3.2

CALAVERAS RESERVOIR 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION (g)

1998

ALLUVIUM CONDITIONS



Base map modified from MapInfo Street Works © 1998 MapInfo Corporation

0 2.5 5

Kilometers

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Figure 3.3

quadrangles are also shown so that the trends in the ground motion may be more apparent. We recommend estimating ground motion values by selecting the map that matches the actual site conditions, and interpolating from the calculated values of PGA rather than the contours, since the points are more accurate.

APPLICATIONS FOR LIQUEFACTION AND LANDSLIDE HAZARD ASSESSMENTS

Deaggregation of the seismic hazard identifies the contribution of each of the earthquakes (various magnitudes and distances) in the model to the ground motion hazard for a particular exposure period (see Cramer and Petersen, 1996). The map in Figure 3.4 identifies the magnitude and the distance (value in parentheses) of the earthquake that contributes most to the hazard at 10% probability of exceedance in 50 years on alluvial site conditions (*predominant earthquake*). This information gives a rationale for selecting a seismic record or ground motion level in evaluating ground failure. However, it is important to keep in mind that more than one earthquake may contribute significantly to the hazard at a site, and those events can have markedly different magnitudes and distances. For liquefaction hazard the predominant earthquake magnitude from Figure 3.4 and PGA from Figure 3.3 (alluvium conditions) can be used with the Youd and Idriss (1997) approach to estimate cyclic stress ratio demand. For landslide hazard the predominant earthquake magnitude and distance can be used to select a seismic record that is consistent with the hazard for calculating the Newmark displacement (Wilson and Keefer, 1983). When selecting the predominant earthquake magnitude and distance, it is advisable to consider the range of values in the vicinity of the site and perform the ground failure analysis accordingly. This would yield a range in ground failure hazard from which recommendations appropriate to the specific project can be made. Grid values for predominant earthquake magnitude and distance should **not** be interpolated at the site location, because these parameters are not continuous functions.

USE AND LIMITATIONS

The statewide map of seismic hazard has been developed using regional information and is ***not appropriate for site specific structural design applications***. Use of the ground motion maps prepared at larger scale is limited to estimating earthquake loading conditions for preliminary assessment of ground failure at a specific location. We recommend consideration of site-specific analyses before deciding on the sole use of these maps for several reasons.

1. The seismogenic sources used to generate the peak ground accelerations were digitized from the 1:750,000-scale fault activity map of Jennings (1994). Uncertainties in fault location are estimated to be about 1 to 2 kilometers (Petersen and others, 1996). Therefore, differences in the location of calculated hazard values may also differ by a similar amount. At a specific location, however, the log-linear attenuation

CALAVERAS RESERVOIR 7.5 MINUTE QUADRANGLE AND PORTIONS OF ADJACENT QUADRANGLES

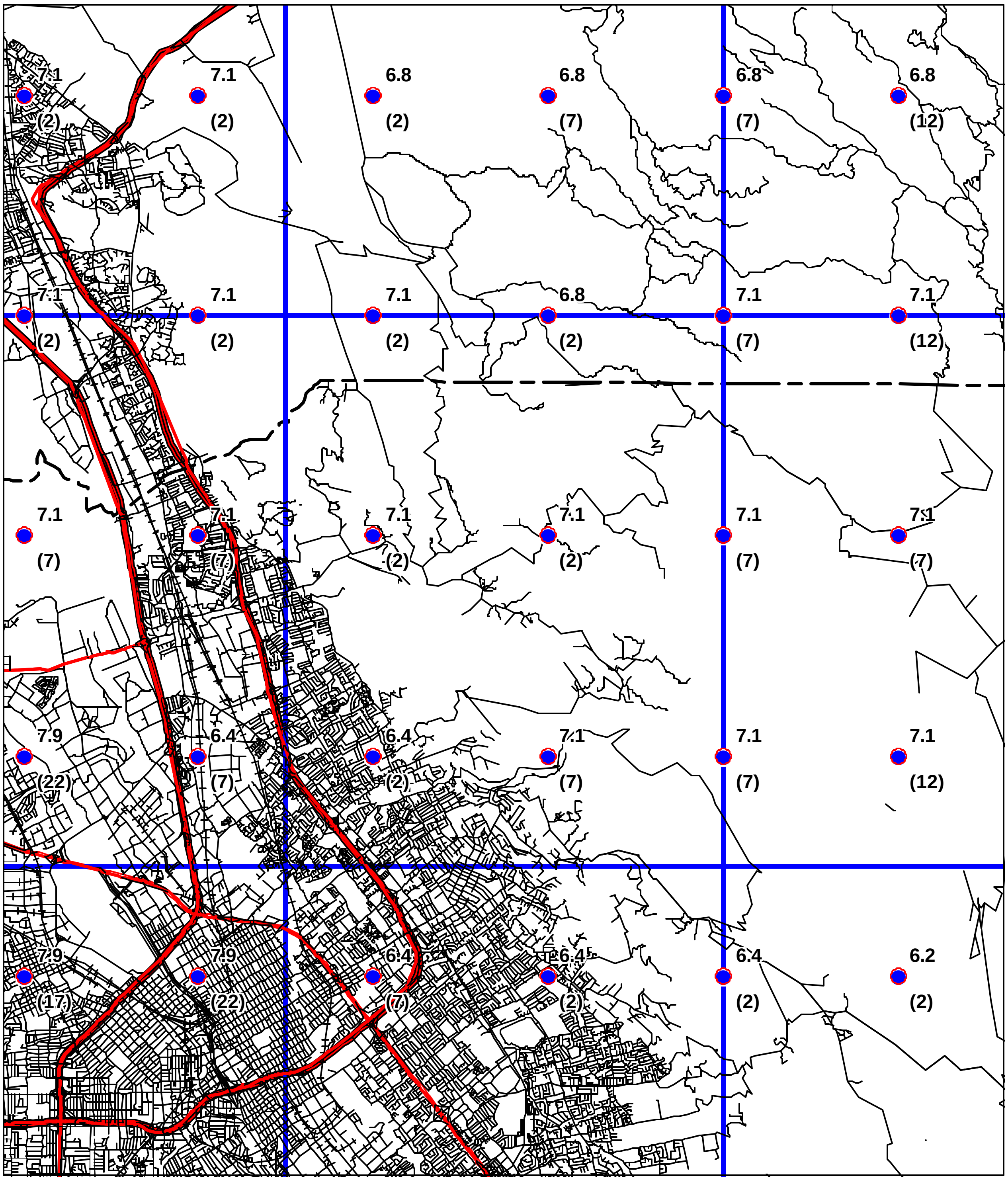
10% EXCEEDANCE IN 50 YEARS PEAK GROUND ACCELERATION

1998

PREDOMINANT EARTHQUAKE

Magnitude (Mw)

(Distance (km))



0 1.5 3

Miles

Department of Conservation

Division of Mines and Geology

Figure 3.4

of ground motion with distance renders hazard estimates less sensitive to uncertainties in source location.

2. The hazard was calculated on a grid at sites separated by about 5 km (0.05 degrees). Therefore, the calculated hazard may be located a couple kilometers away from the site. We have provided shaded contours on the maps to indicate regional trends of the hazard model. However, the contours only show regional trends that may not be apparent from points on a single map. Differences of up to 2 km have been observed between contours and individual ground acceleration values. *We recommend that the user interpolate PGA between the grid point values rather than simply using the shaded contours*.

3. Uncertainties in the hazard values have been estimated to be about +/- 50% of the ground motion value at two standard deviations (Cramer and others, 1996).

4. Not all active faults in California are included in this model. For example, faults that do not have documented slip rates are not included in the source model. Scientific research may identify active faults that have not been previously recognized. Therefore, future versions of the hazard model may include other faults and omit faults that are currently considered.

5. A map of the predominant earthquake magnitude and distance is provided from the deaggregation of the probabilistic seismic hazard model. However, it is important to recognize that a site may have more than one earthquake that contributes significantly to the hazard. Therefore, in some cases earthquakes other than the predominant earthquake should also be considered.

Because of its simplicity, it is likely that the SPPV method (DOC, 1997) will be widely used to estimate earthquake shaking loading conditions for the evaluation of ground failure hazards. It should be kept in mind that ground motions at a given distance from an earthquake will vary depending on site-specific characteristics such as geology, soil properties, and topography, which may not have been adequately accounted for in the regional hazard analysis. Although this variance is represented to some degree by the recorded ground motions that form the basis of the hazard model used to produce Figures 3.1, 3.2, and 3.3, extreme deviations can occur. More sophisticated methods that take into account other factors that may be present at the site (site amplification, basin effects, near source effects, etc.) should be employed as warranted. The decision to use the SPPV method with ground motions derived from Figures 3.1, 3.2, or 3.3 should be based on careful consideration of the above limitations, the geotechnical and seismological aspects of the project setting, and the “importance” or sensitivity of the proposed building with regard to occupant safety.

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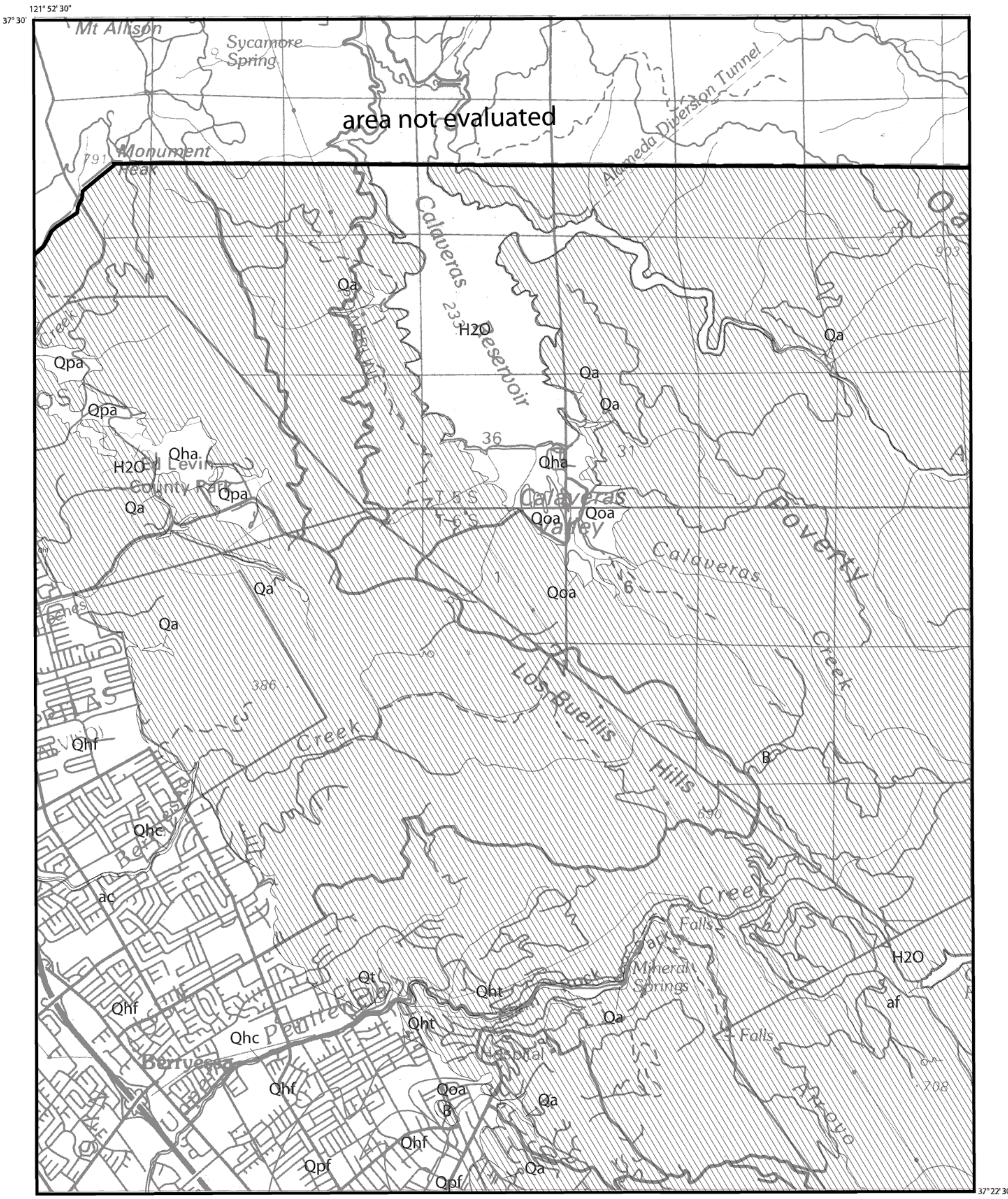


CALAVERAS RESERVOIR QUADRANGLE

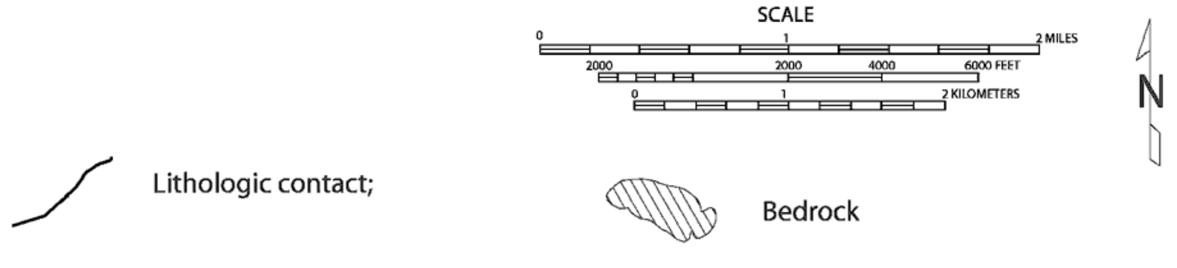
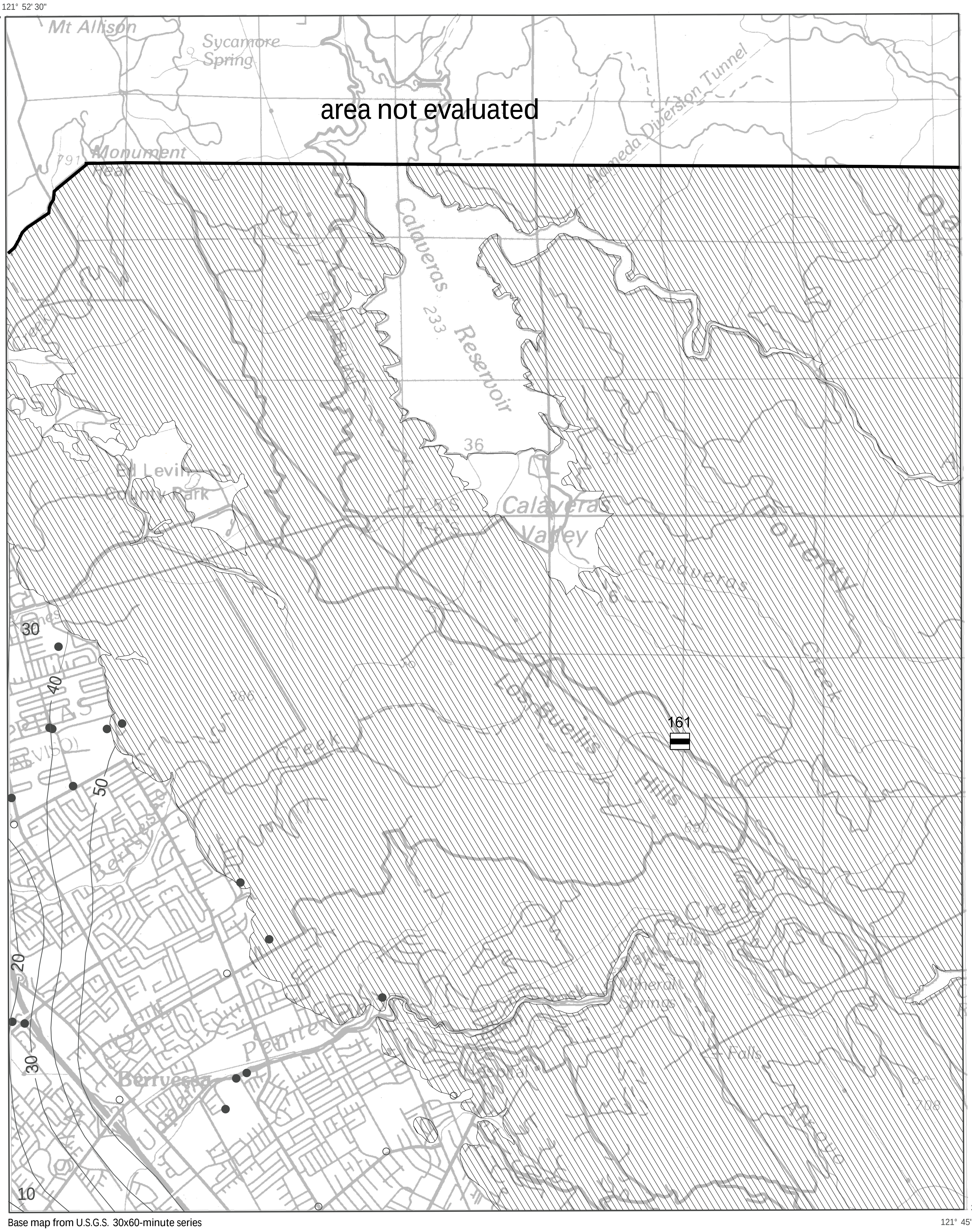


Plate 1.1 Quaternary geologic map of the Calaveras Reservoir 7.5-minute Quadrangle, California. Modified from Knudsen and others (2000).



Base map from U.S.G.S. 30x60-minute series

CALAVERAS RESERVOIR QUADRANGLE

SCALE

0 1 2 MILES
2000 0 2000 4000 6000 FEET
0 1 2 KILOMETERS

N

Bedrock

—10— Depth to ground water, in feet

● Geotechnical borings used in liquefaction evaluation

○ Water-level data provided by the Santa Clara Valley Water District

161 Historical ground cracks not clearly associated with landslides, lateral spreads, settlement, or primary movements. Number assigned to ground failure site adapted from Youd and Hoose (1978) by Knudsen and others (2000).

Plate 1.2 Depth to historically high ground water and locations of boreholes used in this study, Calaveras Reservoir 7.5-minute Quadrangle, California.

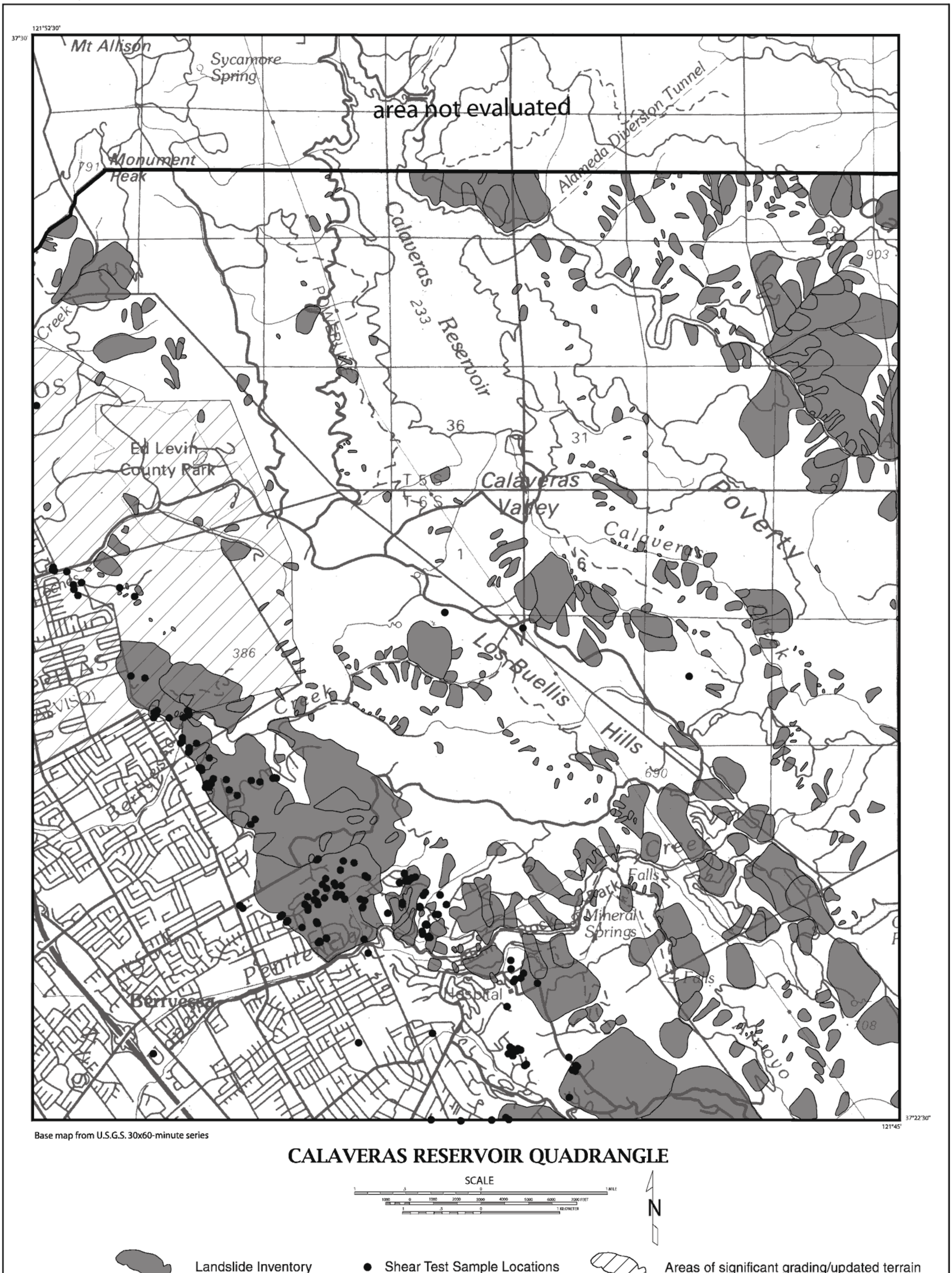


Plate 2.1 Landslide inventory, shear test sample locations and areas of signifacant grading, Calaveras Reservoir 7.5-minute Quadrangle